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FIREFIGHTING MODULE DEVELOPMENT

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16. ABSTRACT <p>The Firefighting Module development was sponsored by the United States Coast Guard and the Maritime Administration. The module is a lightweight, compact, self-contained, helicopter-transportable unit for fighting harbor and other specialty fires as well as for use in emergency water pumping applications. Units have been fabricated and tested. A production-type unit is now undergoing an inservice evaluation and demonstration program at the port of St Louis. Its primary purpose is to promote enhanced harbor fire protection at inland and coastal ports. This paper describes the module and its development.</p>			
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TECHNICAL MEMORANDUM

FIRE FIGHTING MODULE DEVELOPMENT

INTRODUCTION

A lightweight, helicopter-transportable, firefighting module has been developed to promote improved harbor fire protection for inland and coastal waterways. This project was jointly sponsored by the U.S. Coast Guard (USCG) and the Maritime Administration. The module is unique in its lightweight compact size (1600 lb dry), helicopter transportability to a fire site, self-contained fuel supply, 2500 gal/min flow capability, and ability to draft water up to a 20-ft evaluation above the sea. Flow is provided by a lightweight 2-stage aerospace type pump driven by a 370 h.p. gas turbine engine. A prototype module has been delivered to the U.S. Coast Guard, and a demonstration program was completed. An improved commercial module has been fabricated for the Maritime Administration and was delivered to the inland port of St. Louis where a demonstration and in-service evaluation program is underway.

Module applications include: fighting harbor, forest, petrochemical, and offshore platform fires; providing portable emergency booster, vessel dewatering, and flood control pumps; converting patrol boats into low cost fireboats; and possible use in oil spill cleanup.

In the spring of 1975, the USCG contacted NASA about participation in the development of a lightweight prototype, firefighting module. The USCG felt that existing NASA technology could be applied in such a development program. The idea was to develop a lightweight unit which contained its own fuel supply, firefighting equipment and could, if necessary, be air-lifted by helicopter to the scene of a fire.

This document describes the module, its test, and development.

FEASIBILITY STUDY/DESIGN REQUIREMENTS

A feasibility study was completed and reported to the USCG in July 1975. Its purpose was to determine if the basic USCG requirements could be achieved and to define an acceptable design approach.

The initial investigation was to locate a suitable off-the-shelf pump and engine. The available standard commercial pumps of sufficient flow and suction lift capability required low rotational speeds resulting in large, heavy, and cumbersome configurations. Among the other pump approaches

considered were standard fire pumps, modified liquid oxygen transfer pumps with centrifugal impeller and inducer, modified rocket engine turbo-pumps, axial flow marine propulsion waterjet pumps with inducer and bypass, and a new pump tailored to the application. In addition to the new pump design, two other modified pumps appeared to be usable.

The engines investigated were gas turbine, turbocharge diesel, aircraft air-cooled, and automotive internal combustion. Due to the increased fire hazard of gasoline, this type engine was dropped from consideration. The reciprocating diesel engine weight was prohibitive within the guidelines of module airlift capability by helicopter. Several potentially usable off-the-shelf gas turbine engines were identified.

Module packaging layouts were prepared utilizing an attractive engine/pump combination. The results indicated the USCG performance, weight, and dimension requirements could be achieved. The USCG then approved the basic approach, and a module procurement specification was prepared, approved, and released to industry for proposals.

The specification defined the following basic requirements:

- 1) Weight - 3000 lb maximum with fuel and equipment
- 2) Size - 5 x 5 x 8ft
- 3) Flow - 1500 gpm minimum at 150 psi nozzle pressure
- 4) Water Lift - 12 ft minimum; 20 ft design goal
- 5) Life - 100 hr minimum operating time without maintenance. 15 yr storage in coastal environment.
- 6) Fuel Supply - 3 hr minimum operating time per fuel load.
- 7) Basic Simplicity of Operation -

DEVELOPMENT SUMMARY

The USCG contacted NASA/MSFC during the spring of 1975 concerning development of a lightweight firefighting module. MSFC performed a feasibility study which indicated development of the module was feasible.

A design specification was prepared and released to industry for proposal. A contract was awarded to Northern Research and Engineering Corporation (NREC) in June 1975, for the design, fabrication, and test of a prototype module. The effort included design of the following sub-systems: pump, water system, fuel and lube system, control system, and a module housing.

After design completion, the module was fabricated and subsystem testing was completed in December 1978. The module, after completion of acceptance test in January 1979 at a dock site in Boston Harbor, was transferred to the USCG Fire and Safety Detachment in Mobile, Alabama, for additional dock site and shipboard testing. This testing was completed in July 1979.

In the meantime, NREC and Aviation Power Supply (APS) initiated a combined effort to fabricate and market a module for the commercial market. An APS market survey indicated the need for a higher flow pump than the USCG pump. The Cameron Pump Company, a sister division of NREC under the parent company Ingersoll-Rand, became involved in the higher flow pump development, a modified NREC pump.

The Maritime Administration (MARAD) became interested in the module as a method of improving inland and coastal harbor fire protection. With MARAD funding, a NASA contract was then awarded to APS in December 1978 to fabricate a commercial type module with a higher flow pump. The module was fabricated and a 100-hr endurance test completed in May 1980.

As a part of the MARAD program, a NASA no-cost-contract was awarded to the inland port city of St. Louis in April 1980, to perform a module demonstration and inservice evaluation program.

After completion of the endurance test, the MARAD module was refurbished and shipped, along with its support trailer, to St. Louis for the evaluation program. The first of two demonstrations was completed in October 1980. After completion of the demonstration, the module will be returned to service as a St. Louis Firefighting Apparatus for a minimum period of 2 yr.

In April 1980, a contract was awarded to APS to modify the USCG module to incorporate the MARAD type pump and the new control system and suction hose. It will be used as a spare for the MARAD module. The module appears to have application in oil spill cleanup. A feasibility study has been initiated to further pursue this effort. Figure 1 is a chart showing the module development milestones.

MODULE DESCRIPTION

A prototype module has been developed and delivered to the USCG. An improved module has been fabricated and delivered to the Maritime Administration. The Maritime Administration module, the latest configuration, is described in this section. Figures 2, 3, and 4 are photographs of the basic module. It is a lightweight, high performance, skid mounted, gas turbine powered pumping system delivering up to 2500 gal/min of water at 150 psi discharge pressure. Water source can be any open stretch of fresh/saltwater or a high capacity fire hydrant. The module can self-prime and draft water up to a 20-ft lift from the sea. It is self-contained

and can operate for 4 hr at maximum flow without refueling. The overall size of the basic module is 4 x 5.4 x 6.8 ft, and it weighs 1600 lb dry. The module is designed for operation from a river bank, the bed of a light truck, trailer, dock, or the deck of a barge or boat. It can be transported by truck, trailer, boat, forklift, or sling load from a helicopter.

Module Principle of Operation

Figure 5 is a block diagram of the module system. Figure 6 shows the USCG module in operation on a 32-ft patrol boat. Figure 7 shows the module in operation on the deck of a St. Louis fire boat. Upon arrival at a fire site, the suction hose is deployed into the water and module operation is then initiated. The starter/generator spins the engine up to 15 percent speed, at which time ignition occurs. The engine accelerates to 60 percent speed, at which time the starter switches from starter to generator mode. The operator then initiates the prime sequence by depressing and holding a spring loaded prime switch. This switch opens a prime valve and turns on a small pumping system. The pump evacuates air from the suction hose and dumps it through a small tube to the module exterior. A large check valve in the fire pump discharge line seals off the discharge port - thus as the primer operates, it pulls a partial vacuum on the suction hose. Atmospheric pressure acting on the water surface then forces water up the suction hose until it reaches the fire pump.

The fire pump is now running at approximately 60 percent and begins pumping at this time. This pressurizes the discharge hose and causes flow through the water cannons. The prime switch is released at this time. This shuts off the primer and closes the prime valve. The desired engine power level can then be selected.

The module can be operated either in the automatic or manual operating mode. In the automatic mode, the pump discharge pressure can be set to a desired value, and this pressure is then automatically maintained by the module controller. Thus, if a discharge line valve or equivalent were opened or closed, the controller would reposition the engine power level to maintain the original pressure setting. In the manual setting, the engine is set to a speed as determined by the hand operated throttle setting.

The control panel provides a monitor of specific module operating conditions and provides fault isolation or caution/warning indicator lights.

Since the engine turbine blades rotate at high speed, a fuel control governor is provided to protect engine and operator personnel by restricting speed in the event of a sudden unloading of the system, such as loss of pump prime. A redundant overspeed system independent of the engine is also provided as a backup. Furthermore, a halon fire suppression system is located in the module to extinguish an internal fire if one should occur.

Module Physical Arrangement

Figures 8 through 16 show the physical arrangement of the module during buildup. The primary structural element is the fuel tank, Figure 8, with longitudinal stiffeners which serve as forklift tunnels. Four shock-mounted skids are mounted to the tunnel, one at each corner (Fig. 11). The engine and pump are integrally mounted to a lightweight frame (Figs. 9 and 10) which is bolted to the fuel tank.

A firewall separates the engine combustion chamber from the pump section of the module. The engine gearbox, fuel control system, starter/generator, exhaust ducts, prime valve/prime pump, engine oil cooler, air eductor, oil pump, pump volute discharge line, and check valve (Figs. 11 and 12) are located in the combustion chamber section. The engine compressor, inlet demister filters, front pump shock mounts, oil reservoirs, battery, and halon bottle are located in the pump section.

Above the combustion chamber section is an enclosure (Figs. 12, 13, and 14) which contains the control relays and a control panel in one section and the exhaust stacks in the other. Just forward of this box is the water discharge manifold tee (Fig. 12). For additional control of water flow, three valves are located, one on each side of the tee (Fig. 2). A rack is bolted to each side of the module, one for suction hose stowage (Fig. 15); and the other (Fig. 16) for stowage of discharge hose, float pickups, and other firefighting equipment.

The module consists of the following major assemblies:

- 1) Module Housing/Fuel Tank
- 2) Engine/Gearbox/Fuel Control
- 3) Pump
- 4) Lubrication System
- 5) Priming System
- 6) Module Control System
- 7) Internal Fire Extinguishing System
- 8) Ancillary Firefighting Equipment.

Module Housing/Fuel Tank

The module frame houses all module components excluding the fuel tank and ancillary firefighting equipment. The frame can be unbolted from the fuel tank and removed as an assembly with all components intact (Fig. 10). Likewise, the cabinet rack for housing firefighting equipment is removable as a unit. The control box assembly (Fig. 14) also is removable as a unit. Two removable salt air demister/filters made of monel are located on each side of the unit. The engine compressor draws air through the filters and into the engine for combustion. The filters are designed to protect the engine by removing contaminants, particularly salt in coastal areas, from the entering air.

The hot engine section of the module is separated from the pump section by a fire wall. This prevents mixing of the engine compressor intake gas and the oil cooler gas, and prevents additional heating of compressor intake caused by the hot engine. Figure 17 is an air flow schematic illustrating the preceding.

Removable panels/doors are located on all sides of the module providing excellent component access. Panels/doors are lined with insulated fiberglass duct board with a resulting reduction in engine intake noise. The frame is made of 6061T6 aluminum; the panels and fuel tank are made of 5052H34 aluminum.

The fuel tank (Fig. 8) is a wide shallow design with a slight V which provides a fuel pickup trough. Two pickups are provided - each is equipped with a float valve to prevent air from entering the fuel line when one end of the module is higher than the other. The trough and dual pickup (Fig. 18) permits operation of the module when tilted in any direction up to 20 degrees from the horizontal. The shallow tank which forms the main base of the module has a 155 gal diesel fuel capacity. Internal baffles minimize sloshing. Two tank air vents are located on either end. The fuel tank, the heaviest module component (265 lb dry and approximately 1200 lb when filled) gives the module a low and stable center of gravity. A tank drain plug is located in the fuel trough. Two 7- x 3-in. rectangular forklift tunnels are welded to each side of the module and extend its full length. Two shock-mounted skids are attached to each tunnel.

Engine/Gearbox/Fuel Control

The engine is a model 250-KB Allison industrial gas turbine which is rated at 370 shaft hp for continuous operation at turbine outlet temperatures of 1360°F or less. It is a slightly modified version of the 250-C20B which has been used extensively in helicopter applications. The unit is an internal combustion turboshaft engine of the free turbine type (Fig. 19). The gas generator is composed of a combination 6-stage axial, single stage centrifugal flow compressor directly coupled to a 2-stage gas generator turbine. The power turbine is a 2-stage free turbine that is gas coupled to the gas generator turbine. The engine has a single combustion chamber. The gas generator rotor speed is 50,000 rpm and power turbine rotor, 32,920 rpm, at the 100 percent continuous power level.

The power turbine rotor furnishes the output power of the engine through the integral reduction gearbox at 6584 rpm to an internal spline drive at the front of the gearbox. A quill shaft mated with spline drives the fire pump. Engine accessories driven off the power turbine gear train are the power turbine tachometer generator and the power turbine governor. The gas producer gear train drives the compressor, fuel pump, gas producer tachometer, the gas producer fuel control, and the engine lubrication oil pumps. The oil pumps are mounted internally. The starter drive and fire pump oil pump drive are also in this gear train. Both gear trains are housed in a single gearbox.

This gearbox, made of magnesium, serves as the structural support for the engine. The power turbine gear train consists of two stages of helical gearing. The helix angles of these gears are such that a forward axial thrust is produced on a torque meter shaft to which gears are mounted. A unique feature of the gearbox is that this axial thrust is transmitted to a sliding cylinder counterbalanced by oil from the lubrication system. The resulting oil pressure can be read on the torque meter giving an instantaneous direct reading of engine torque, which knowing rpm, can be converted to horsepower.

The principles of engine operation are as follows:

- 1) Air enters the engine through the compressor inlet and is compressed. It is discharged through a scroll type diffuser into two external ducts which convey the air to the combustion section.
- 2) Air enters the single combustion liner, located at the rear of the engine through holes in the liner dome and skin. This air is mixed with fuel sprayed from the fuel nozzle to support combustion.
- 3) Combustion gases move out of the combustion liner to the gas producer turbine, then expand on through the power turbine and discharge through the twin ducts of the exhaust collector.

Engine cooling is provided as follows (Fig. 17): Air is drawn in through the module salt air demisters at approximately 2700 cfm at full power. This air circulates to the compressor inlet where it enters the engine. Oil cooling is provided by air flow across the oil cooler. Flow is induced by the air eductor located around the engine exhaust stacks. It circulates across the engine providing additional convective cooling.

The major engine fuel control system components are the fuel pump, gas producer fuel control, power turbine governor, and fuel nozzle, as shown in Figure 20. This system controls engine power output by controlling the gas producer speed. Gas producer speed levels are established by the action of the power turbine fuel governor which senses power turbine speed. The power turbine speed (directly geared to pump speed) is selected by the module operator via a control panel mounted throttle link to the power turbine governor lever. The power required to maintain this speed is automatically maintained by power turbine governor which schedules the gas producer speed to a changed power output to maintain output shaft speed via metered fuel flow.

Fuel flow for engine control is established as a function of compressor discharge pressure (P_C), engine speed (gas producer, N_1 , and/or power turbine, N_2). Variations of the fuel flow schedules are obtained by modulating the P_C to P_X and P_Y pressures in the control through the action of a bleed-down circuit actuated by the governors. An overspeed orifice bleeds P_Y pressure from the governing system of the gas producer fuel control. Bleeding P_Y pressure at the power turbine governor gives the fuel control system a rapid response to overspeed conditions.

The hardware interface between the engine fuel control system and the module electronic control system is as follows: A control cable links module control panel throttle to power turbine governor lever. A proportional bleed valve is added to the P_y pressure line, and a solenoid shutoff valve is located in the engine fuel line. These valves are controlled by electronic signals from the module control system. This is discussed in more detail in the section describing the module control system.

Pump

The pump is a unique two-stage, two-speed unit designed for the fire-fighting module. There were four main design drivers which resulted in its present configuration:

- 1) 20-ft suction lift
- 2) Minimum weight
- 3) High flow
- 4) Requirement to integrally mount pump to engine.

The first stage is a low speed axial inducer; the second stage is a high speed mixed flow impeller with a scroll type diffuser.

The inducer provides the required net positive suction head for the main impeller. At 100 percent speed, the main impeller rotates at 6584 rpm and the inducer at 2626 rpm. The inducer-impeller combination is mounted in tandem on the same centerline. The engine quill shaft drives the main impeller which in turn drives the inducer via an integral planetary gear train mounted within the inducer stator. A cutaway of the pump is shown in Figure 21.

The bearings, gears, and splines in the pump are pressure lubricated by a dry sump lubrication system.

Mechanical Arrangement

The inducer and the impeller are mounted on their respective shafts on a common centerline. The impeller, 316 stainless, is mounted on a stainless shaft which is supported in the rear by a set of triple 208 HDM barden ball bearings. They provide thrust as well as radial support. The other end is supported by a journal bearing. Thrust loads are reduced by vanes incorporated on the rear end of the impeller.

Back-to-back spring loaded viton lip seals are the main bearing seals. A carbon wear ring seal is positioned between the main seals and the pump flow stream. The cavity between them is vented overboard. This

arrangement allows any water leaking past the wear ring to be vented so that little if any water pressure is allowed to buildup on the main seals, thus reducing the probability of water leaking into the bearing cavity. During normal pump operation, a small water flow can be seen exiting the seal drain line.

The inducer material is titanium; its hub is cone shaped which allows room for mounting the planetary gear train at the large rear end of the inducer bearing housing. The inducer shaft is supported on the front end by a pair of 206H ball bearings with the other end mounted to a ring gear which is supported by idler gears (Fig. 22) in the gear train. The idler gears, which are mounted in a gear carrier, are arranged around an input gear which is attached to the main impeller shaft. The rear of the inducer shaft then floats off the gear train.

The gear train and inducer bearing have the same type seal arrangement as the impeller.

The pump housing is A356 aluminum. A surge chamber is mounted to the pump inlet to minimize pump pulsation.

The inducer, inducer shaft, gear train, and bearing can be easily removed from the front end of the pump without any module disassembly. To remove the impeller shaft bearings, however, requires pump removal. The excellent access to module components facilitates this job. Also, the quill shaft can be removed/installed from the rear of engine which makes an otherwise tricky task very simple.

Pump Performance

The pump had several significantly divergent requirements:-- light-weight, compact size, high flow, and high lift. In conventional pumps, the first three are frequently achieved by relatively small-diameter, high-speed impellers and the latter by larger impellers with slow rotational speeds. In order to satisfy these requirements in a single pump, a two-stage pump was designed with each stage rotating at different speeds. The first stage is a low-speed, axial-flow inducer (Fig. 21) with a diameter of 9 in. which rotates at 2626 rpm at 100 percent speed. The second stage is a relatively high-speed, mixed-flow impeller (Fig. 24) with a diameter of 7 in. which rotates at 6584 rpm at 100 percent speed.

The normal maximum pump speed is 90 percent resulting in an inducer speed of 2363 rpm and an impeller speed of 5926 rpm. The inducer and impeller specific speeds are 4046 and 3701, respectively.

The inducer has a very low net positive suction head, NPSH, requirement which allows it to operate at up to a 20 ft suction lift. It provides a discharge net positive suction head available, NPSHA, (Fig. 25) adequate to meet the needs of the impeller.

Figure 26 is a plot of the pump discharge pressure versus flow, H/Q curve, which was measured during module acceptance test. This curve was taken at 90 percent of maximum engine rpm. Engine horsepower is rated at sea level and 60°F; at higher temperatures less horsepower is available. The module has, therefore, been set up for continuous pump/engine operation at 90 percent speed.

Lubrication System

Two independent lub oil systems are utilized, one for the engine, the other for the fire pump; see figure 27. They are both dry sump systems which use the same type oil and similar, but separate, lube oil reservoirs.

The engine oil pump and scavenge element are located inside the engine gearbox. Oil is picked up at this point and is delivered under pressure to a filter mounted atop the gearbox and to various internal rotating engine components. It then flows through the air cooler, to the reservoir, and back to the pump.

The oil pump for the fire pump lubrication system is mounted to and driven by an accessory drive pad on the engine gearbox. The pump draws lubricant from the reservoir and pumps it through a filter and into a heat exchanger mounted inside the engine oil reservoir. Lubricant then flows to a tee fitting. In one direction, the oil passes through a reducer which lowers flow to 0.5 gpm at 4 psi maximum. This line continues to the inlet port atop the pump. Oil flows across the inducer diffuser vane into the pump planetary gearbox. It then flows into the center of the pump shaft where it is distributed to the pump bearings and collected at two scavenge points.

The other side of the tee provides oil to a scavenge eductor loop. The pressurized oil passes through a check valve to an eductor which creates a vacuum on the two scavenge points on the pump. The oil then returns to the oil reservoir and back to the oil pump.

Priming System

The module main pump is capable of operating at a suction water lift of 20 ft once prime is achieved. This means that the module can operate on a dock site with the pump centerline located 20 ft above the waterline. A small pumping system is required to prime the main pump for initial operation. This system can provide up to 22 in. of mercury vacuum.

In principle, the primer evacuates air out of the module inlet suction line, thus creating a partial vacuum within the suction line. Atmospheric pressure acting on the water's surface then pushes water up as the air

is removed. The air is discharged external to the module. A large check valve located in the main pump discharge line seals the main pump during prime. Once prime is achieved the pump discharge pressure overcomes a spring force and opens the check valve.

Two different prime pump systems have been utilized. One is an eductor system which is powered by engine compressor bleed air (Fig. 28). The other system uses a dc motor driven vane type pump (Fig. 29).

In order to reduce battery drain during start, prime is not initiated until the engine generator is providing electrical power. The engine utilizes a single combined starter/generator. It initially functions as a starter. However, once fuel ignition is achieved and the engine is running at 60 percent pump speed, the starter automatically switches to the generator mode. At this time the primer is switched on.

The main pump is directly coupled to the power turbine through a gearbox; thus, when fuel ignition is achieved, the main pump is rotating. As water reaches the main pump, flow commences; when water flow from the water cannons is observed, the prime switch is released. This shuts off the prime pump and closes the prime valve. The function of the prime valve is to shut off the water flow between the two pumps once prime is achieved; otherwise, water would flow through the primer air discharge line and be continuously dumped adjacent to the module.

Module Control System

This system allows the operator to start, stop, and control pump flow and pressure. It also provides an automatic shutdown feature in the event of loss of prime or shaft failure. Gauges and fault isolation indicator lights are provided on the instrument panel (Fig. 13) and elsewhere to keep the operator informed of module operating status. A throttle lever, pressure dial, and other operator controls are also located on the instrument panel. Figure 30 describes the operator instrumentation.

Panel lights for night viewing are also provided. The control system is activated by a panel key switch and the start button. When the key is switched on, all the fault isolation indicators are illuminated. This provides an indicator check. The indicators are cleared by pushing a reset button. Indicators can be cleared at any time provided a light was not caused by a malfunction which is still present. Figure 31 shows a typical start sequence.

A trickle charger is provided to maintain an adequate battery charge during long down times. An amp meter and press-to-test-button, for checking battery charge status, are located behind the instrument panel. A fuel gauge and engine torque meter are located on the module exterior next to the fuel fill fitting.

Loss of pump suction, caused by wave action or other conditions, could instantly unload the pump and allow rapid engine acceleration resulting in overspeed and possible damage to the module. Also possible, although remote, is the shearing of the pump shaft or quill shaft with the same end result. An automatic shutdown system is provided to prevent this occurrence. The engine governor system is designed to prevent overspeed beyond 105 percent. The module controller provides an independent, redundant shutdown system. An automatic pressure control system allows the operator to dial in a pump discharge pressure. The pump then automatically maintains this pressure, including conditions under which the downstream discharge hose resistance is changed, for example by opening or closing a discharge valve. The controller senses pump discharge pressure and regulates engine fuel flow and power to maintain this pressure.

The following sensors are provided as inputs to the control system:

- 1) Speed (rpm)
 - a) Gasifier turbine (N_1)
 - b) Power turbine (N_2)
 - c) Pump (impeller) (N_p)
- 2) Temperature
 - a) Pump oil (POT)
 - b) Pump water (PWT)
 - c) Engine oil (EOT)
 - d) Turbine outlet (TOT)
- 3) Pressure
 - a) Engine oil (EOP)
 - b) Pump oil (POP)
 - c) Pump discharge (PDP).

Each of these sensors is independent of engine provided sensors except for TOT and EOT. The speed sensors are failsafe. If one fails, it shuts down the engine. Figure 32 describes the controller sequencing during start and defines the fault isolation parameters.

As stated in the engine description, the module control system hardware interface between the module control system and the engine controller is as follows: A push/pull control cable links module control panel throttle to the power turbine governor lever. A module proportional bleed valve is located in the engine system P_y pressure line. A solenoid shut-off valve is located in the engine fuel line (Fig. 20).

Automatic pressure control is provided by electronically comparing the pump discharge pressure with the control panel pressure setting. If the pump discharge pressure is below the panel setting, the controller steps the proportional valve to bleed less P_y which, through the engine controller, increases governor fuel flow thus increasing engine rpm and raising pump discharge to the set value. If the pump discharge pressure is above the panel setting, the proportional valve bleeds less P_y and the engine rpm drops the appropriate amount.

Automatic overspeed is provided by electronically comparing the gasifier turbine, power turbine, and pump speeds with present values of each programmed into the controller. In the event of overspeed, the controller sends a signal to the fuel solenoid valve which closes in 11 m/sec and shuts down the engine.

Internal Fire Extinguishing System

The purpose of the system is to provide quick response fire protection for the module. It consists of a sensing element, manual switch, control unit, and halon fire extinguisher.

When the average temperature of the sensing element reaches 600°F, or a 1-ft section reaches 750°F, the squib is automatically fired by the control unit. This discharges the halon from the fire extinguisher. In addition to the automatic system, a manual push button is located on the instrument panel to permit the operator to discharge the fire extinguisher.

Ancillary Firefighting Equipment

The module housing is equipped with an open equipment mounting cabinet on one side and a suction hose rack on the other. As configured for the MARAD module, the hose rack supports six 8-ft sections of suction hoses. The cabinet supports two float type water pickups and 4 sections of 4-in. diameter fire hose, each 25 ft long. Space is also available to store two water cannons in the cabinet. Both the rack and cabinet are easily removable (Figs. 15, 16, 33, and 34). Space is also available for storing other miscellaneous equipment as required for certain missions.

USCG MODULE TESTING

Since the module was a new development, a rather extensive test program was required within the constraints of limited funding. The following tests were performed:

- 1) Pump

- 2) Prime system
- 3) Control system
- 4) Module performance
- 5) Module endurance
- 6) Module acceptance
- 7) USCG demonstration.

Pump

Early pump builds incorporated various changes in seeking increased efficiency and performance. The most significant improvements were the results of reducing interstage leakage and impeller to shroud clearance. Builds 1 through 5 were tested in a closed loop test setup. During this time, problems were experienced with test loop leakage, flow meter accuracy, and control of bubbles. Also, build 2 failed because of reverse installation of the engine/pump coupling. Therefore, when a module housing became available further testing was performed open loop at dock site.

Build 5 was shipped to APS for the commercial module. Build 4 was installed in the USCG module for performance test and a 100-hr endurance test. A high speed gear set was installed in the engine gearbox to increase the pump rotational speed from 6315 to 6584 rpm, in order to increase performance.

Prime System

The prime eductor was bench tested. It was necessary to resize the throat to obtain the necessary vacuum for a 20-ft lift in less than 2 min. During module testing, air was trapped in the float switch cavity preventing a prime complete signal from initiating. The float switch was replaced with a pressure switch located downstream of the pump.

Control System

The electronic controller was bench tested with a module simulator. The speed controller circuits were sensitive to humidity and the signal level produced by the speed sensors. The printed circuit boards were conformal coated and their sensitivity was modified to be compatible with the sensors. Premature module shutdown was caused by a turbine outlet temperature limit circuit. A time delay was incorporated to allow for the temperature overshoot which occurs during module start.

Module Performance

Module systems were checked at dock site with emphasis on the priming system, control system, and water flow performance.

Endurance Test

The module was set up at a dock site in Boston Harbor. Because of tide fluctuation, water lift varied from approximately 10 to 20 ft. After 45 hr of operation at high lift and full power, the test was suspended because of a loss in performance. Pump teardown revealed that a segment of the main impeller blade was missing and that severe cavitation was occurring. There was evidence of blade fatigue failure probably associated with the cavitation and unbalanced peripheral pressure fields at high back pressure at low flow rates.

The main impeller bearings were heavily damaged with indications of high radial and thrust loads. The pump housing casting was also leaking near a weld repair. The following design changes were initiated:

- 1) Increase the rotating speed of the inducer relative to the impeller speed. This change was to increase the inlet head of the main impeller and improve its cavitation performance.**
- 2) The diameter of the impeller inlet was also increased and the shroud changed to match. This was also expected to improve cavitation performance.**
- 3) Larger main impeller bearings were installed.**
- 4) Housing leak was repaired.**
- 5) A new impeller was installed.**

The pump was rebuilt and a water cannon, nozzle calibration, and performance test were performed. For the first time, the design goal performance of 408 ft of head (177 psi) at 2200 gal/min was achieved.

After 17 hours of operation, the quill shaft spline teeth failed at the engine end. Failure was a result of a combination of causes:

- 1) Quill shaft did not use a full spline.**
- 2) Misalignment.**
- 3) Inadequate hardness.**

An improved longer shaft was manufactured and an improved alignment procedure implemented. The bearings and seals were inspected and found to be in excellent shape; however, the inducer and impeller were showing evidence of cavitation, and one of the inducer blades was cracked near the root. The impeller cavitation was only producing a polishing effect on the blade near its middle on the pressure surface and near the root on the suction side. The inducer was weld repaired and reinstalled.

Up to this time in the test program, a loss of engine power was becoming evident, particularly on warm days. The engine was pulled and shipped back to APS for repair. It was found to deliver 302 hp rather than the design power rating of 346 hp. The engine was disassembled and the first stage rotor blades were burned at the tips. Several other problems were also found. The problem was probably caused by hot engine starts which were caused by ignition at too low a speed and slow acceleration. The engine was repaired and tested at 354 hp.

The module was reassembled and the test resumed. Thirteen additional hours of test time were accumulated during which two more inducer failures occurred.

Inspection and analysis of the failure revealed the following. The inducer blades in the area of the failure were 0.13 to 0.14 less than the design thickness of 0.25 in. This resulted in a steady state root stress of 23,000 psi and a vibratory stress of 4000 psi. This level was sufficient to cause rapid failure by fatigue cracking. The potential fixes were to:

a) Assure sufficient material thickness and change material from A356 aluminum to titanium.

b) Increase material thickness only.

c) Go back and decrease inducer to impeller speed ratio and establish an overall reduced operating envelope to protect the main impeller from cavitation because of the again reduced NPSH available to the impeller caused by reduced inducer rpm.

Fix 3) was implemented because of a lack of funds for implementing 1) or 2).

As a result of funding problems and USCG schedule requirements, it was decided to halt the endurance test at Boston and rerun it after shipment to the USCG Fire and Safety Detachment in Mobile, Alabama.

Module Acceptance Test

During the module acceptance test, the following problems were encountered which caused several weeks delay in the completion of the testing:

1) A new card, which had been improperly calibrated, had been inserted in the electronic controller causing a premature overspeed shut-down. The card was recalibrated to 105 percent overspeed.

2) The starter generator was not charging the batteries. The regulator set point was recalibrated to prevent premature tripping of the circuit breaker.

3) The engine failed intermittently during the starting sequence. This problem was traced to a broken connection in the main wiring harness connector. This connection was repaired along with several other connections.

4) Oil was leaking from the hydraulic actuator. A new O-ring seal was installed.

5) The fiberglass water cannons leaked at the swivel joints and the base support failed. Repairs and shipment were made subsequent to module shipment.

**USCG Demonstration Test at the Fire and Safety Detachment,
Mobile, Alabama.**

The module was shipped to Mobile, Alabama, where a second 100-hr endurance test was to be initiated. Prior to test start, the module remained at dock site, unprotected from the elements for 1 month. This was 42 days since the module was last operated in Boston. When the module doors were opened, 1/2 in. of water was found standing within the module. The pump would not rotate. A wrench was used to rotate the pump and free the seized part. This may have been when the wear ring separated from the main impeller. The test was initiated with some problems with the battery and fuel system loss of prime. After 50 hr of operation, the spark igniter was inoperative. Water had flooded the relay box and damaged electrical components. A new box was installed with better seals.

After 88 hr of operation, the engine voltage regulator was replaced. It had apparently been damaged by the bad relay box. Also, the fuel solenoid valve was replaced; and the turbine outlet temperature thermocouple connector pins at the control box were repaired. After 100 hr, the fuel tank was found contaminated with 4 to 5 gal of water.

The following additional tests were performed at dock site: fuel consumption (Fig. 35), and acoustic noise (Fig. 36). These tests were concluded with 122 operating hours on module.

The next series of tests were onboard the 32-ft USCG Port and Waterways boat to demonstrate its use as a converted fire boat. Basic boat characteristics were as follows:

- 1) Length: 32 ft
- 2) Displacement (Dry): 18,000 lb
- 3) Engine: Twin 200 hp diesels
- 4) Speed: 19 to 23 kn
- 5) Static Thrust: 4500 lb

The module was located on the aft deck (Fig. 5) with one monitor aft and one forward. With this configuration, the boat maneuvered poorly in close quarters. The water cannon thrust overpowered the engine and rudder control of the boat. With one cannon positioned to port and the other to starboard, the boat would rotate at three revolutions per minute. With both monitors in the same direction, the boat would list at 10 degrees and move sideways at 1 to 2 kn. In 2- to 3-ft waves, the maximum boat speed, without losing pump suction, was 3.5 kn. Having the module onboard reduced maximum boat speed from 23 to 19 kn. A significant problem with having the module onboard is that it covers the engine hatches, allowing no access to the engine compartment in case of engine failure or fire.

Additional maneuvering tests were performed with both water cannons located forward and aft (Figs. 37 and 38). Under both conditions, boat positioning was significantly improved and considered acceptable, with the forward location the best because of the captain's visibility forward.

The module was then mounted on the USCG Point Verde, an 82-ft patrol boat, for additional testing. With the water cannons mounted forward and aft, one flowing to port, the other to starboard, the boat could be rotated at 0.5 revolutions per minute. No boat list was observed with both cannons aimed to port or to starboard. The higher freeboard of this boat required 14 ft of suction pipe. A small boat crossed the bow of the Point Verde causing the Verde to roll which overstressed the suction pipe causing a flange to break. The module could not be restarted at this point; therefore, testing was terminated.

A module teardown and inspection was then performed with the following findings:

- 1) Bearings, Main Impeller Shaft - Bearings were severely worn and indicated conditions of radial overload possibly caused by imbalance.
- 2) Corrosion - Damage was noted at the rear of the main impeller as well as at the interface between the stainless steel main impeller diffuser and the aluminum housing. All metallic fasteners and fittings which were neither stainless steel or aluminum were corroded. The main impeller shroud was lightly corrosion pitted.

3) **Impeller Bearing Seal** – During manufacture a stainless wear ring is pressed onto the impeller inner hub. A thin carbon ring seal is mounted between this wear ring and a stainless ring which is pressed onto the pump housing (Fig. 39). The wear ring had separated from its press fit and had frozen to the pump housing ring. The ring seal had worn away and disappeared. This probably caused the impeller out of balance condition and excessive bearing wear.

4) **Impeller** – A small area of cavitation pitting existed on the pressure surface of each blade approximately 1 in. from the trailing edge and 1/2 in. from the trailing edge and 1/2 in. from the hub. Also, there was light wear between the impeller blades and the shroud, probably caused by the worn bearings.

5) **Inducer, Bearings, Seals, and Gear Train** – These components were in excellent condition with no indicated wear.

6) **Quill Shaft** – The engine end of the quill shaft was severely worn. There was no evidence of wear on the engine spline.

MARAD MODULE TESTING

Improvements

The commercial MARAD module incorporated a significant number of improvements as defined below:

1) **Pump Instability** – A surge chamber was incorporated upstream of the pump to improve flow conditions and reduce flow induced vibration, particularly at high back pressure and high lift conditions.

A new impeller with increased blade back slope was incorporated with larger rear vanes. The gear ratio between the impeller and the inducer was again changed to increase the inducer speed, thereby providing an increased NPSH to the main impeller.

2) **Pump Bearing Loads** – Impeller bearing size was changed from a Barden 206 to a 208 size, and the number increased from 2 to 3.

3) **Corrosion and Cavitation** – The impeller diffuser ring was eliminated which solved the corrosion problem caused by the couple between the stainless steel diffuser and the aluminum housing. The materials of the impeller and inducer were changed from A356 aluminum to 316 stainless steel and titanium, respectively. This results in a significant reduction of cavitation wear and eliminates the need for a wear ring insert on the impeller. A splitter van was added to the volute to improve pump stability and performance.

The quill shaft was redesigned and a full spline incorporated. In the USCG design, it was necessary to position the quill shaft between the pump and the engine prior to mating. This made it difficult to mount the pump to the engine. This was changed so that the pump is now mounted to the engine and the quill shaft is then installed from the other side of the engine gearbox.

4) Control System - The control system was completely redesigned eliminating the hydraulic servovalve and utilizing a modulating valve to control engine power by bleeding the control system pneumatics as required. An automatic pressure control system was incorporated.

5) Check Valve - The poppet type check valve was replaced with a simple flapper type.

6) Suction hose - The single rigid 10-in. diameter suction hose was replaced with dual 6-in. flexible hoses which can be equipped with float type pickups for operation in shallow water.

7) Component Access - A modularized housing was incorporated, which divided the module into several basic sections - fuel tank, engine/pump housing, suction hose rack, firefighting equipment cabinet, and a removable control box. This greatly increased component access. The 3/4-in. hose and hose reel were deleted. Also, the relays were relocated to an area not subject to flooding.

8) Self-Contained Fire Extinguisher - A halon system which operates automatically or can be energized manually was incorporated.

Control System Test

A subcontractor to APS, Semco, redesigned the controller based on a unit previously used for off shore platform gas turbine engine control. A breadboard unit was checked out on a black box simulator of the module. The unit was then operated with the module engine and modifications incorporated to achieve satisfactory performance. The controller was then checked during module testing.

Performance Test and Acceptance Test

The module performance test verified the suitability of the pump and controller. This was followed by a module acceptance test. Figure 26 shows the performance curve generated during the acceptance test.

Endurance Test

A number of minor controller problems occurred during a 100-hr module endurance test. Problems were related to improper wiring during manufacturing and poor electrical connections. Controller modifications were made to correct these problems. In addition, the prime pump motor burned out twice because of excess run time caused by controller failure to shutdown the pump. The first occurrence was caused by the main check valve leaking. This was corrected by modifying the method of valve seal attachment. The second occurrence was caused by a leak in the P_y bleed valve. This was corrected by lockwiring a loose nut. The prime pump operation is no longer controlled by pump discharge pressure. The control system was modified; the pump is now operator controlled by a spring loaded manual switch. Concurrently with the endurance test, environmental tests of the controller were conducted per MIL-STD-810C. These included dust, explosion, temperature, shock, vibration, and salt fog. Electromagnetic test per MIL-STD-461A was also performed. The test was successfully completed after several minor problems were corrected.

MARAD Demonstration and Inservice Evaluation

A module demonstration and inservice evaluation test are presently being performed for the Maritime Administration.

The port city of St. Louis was selected for this no-cost contract as a result of a competitive procurement action.

The first of two demonstrations was successfully completed. The module was demonstrated under four different conditions:

- 1) A small converted St. Louis fire boat, the Targee (Fig. 6)
- 2) A barge with five water cannons operating (Fig. 40).
- 3) Drafting water and supplying it to two fire truck pumps through long lines (Fig. 41).
- 4) Operation from a hydrant (Fig. 42).

Also, module mobility was demonstrated by lifting the module by helicopter (Fig. 43) from a barge to the dock site on the Mississippi River levee and return.

Between demonstrations, the module is mounted on a small St Louis fire boat (Fig. 6) for use in St. Louis for harbor fire protection.

Fire Fighting Module Support at KSC

At the request of the director of Kennedy Space Center (KSC), the MARAD module was shipped to KSC for Space Shuttle backup fire protection in the event of a Return to Landing Site (RTL) abort. The module was set up, and a test was successfully performed to verify module readiness to support a RTL abort. The module was then returned to St. Louis.

SUMMARY/RECOMMENDATIONS

The firefighting module development was initiated at the request of the USCG. A prototype module was delivered to and tested by the USCG. A number of deficiencies were found during testing of this unit.

An improved module, utilizing an improved pump, a new controller, and module housing was fabricated for the Maritime Administration and is now undergoing an inservice evaluation and demonstration program at the port city of St. Louis. This program is intended to compare the module with more conventional fire apparatus and to promote improved harbor fire protection.

The prototype USCG module is now being modified incorporating the improved pump and new controller. It was initiated as a spare for the St. Louis demonstration program.

One other module was fabricated for Dow Chemical Corporation and another is being fabricated by the module contractor, Aviation Power Supply, for the port city of Miami. It is recommended that contact be maintained with the city of Miami for the purpose of collecting operational data to supplement that obtained from St. Louis. The Miami module represents the latest operational configuration and Miami has personnel available to provide proper maintenance.

The module has a number of potential applications which include:

- 1) Fire Boat - The module can be mounted on a boat 30 ft or longer, thereby converting it into a fire boat.
- 2) Fire Truck - The module can be mounted on a small truck. The module will operate at reduced capacity from conventional fire hydrants. Also, the module, when drafting from a pond or 2500 gpm capacity fire hydrant, can lift a stream of water up a vertical wall more than 200 ft high.
- 3) Forest Fires - The module can be air lifted by helicopter to remote areas with access to small streams where it can be set up to deliver water approximately 1 mile from the stream.

4) **Emergency Portable Booster Pump** - In case of draught, flooding, or other emergency, the module can be brought in by helicopter, truck, trailer, or boat, as required, and used to pump water.

5) **Vessel Dewatering** - The module can be used to pump out boats in danger of sinking.

6) **Offshore Oil Well Fires** - The module can be brought in by helicopter to fight offshore oil well or other oil field or marine fires.

It is recommended that the St. Louis demonstration test be continued and evaluation data be collected. The module has significant special purpose applications, but is not intended to replace fire pumpers in their normal range of operation.

The module also appears to have application in oil spill cleanup. It is recommended that an oil recovery turbopump be developed pending the results of a feasibility study now in progress. The module would provide energy to drive the pump for off loading tankers or in use as an oil skimmer (Figs. 44 and 45).

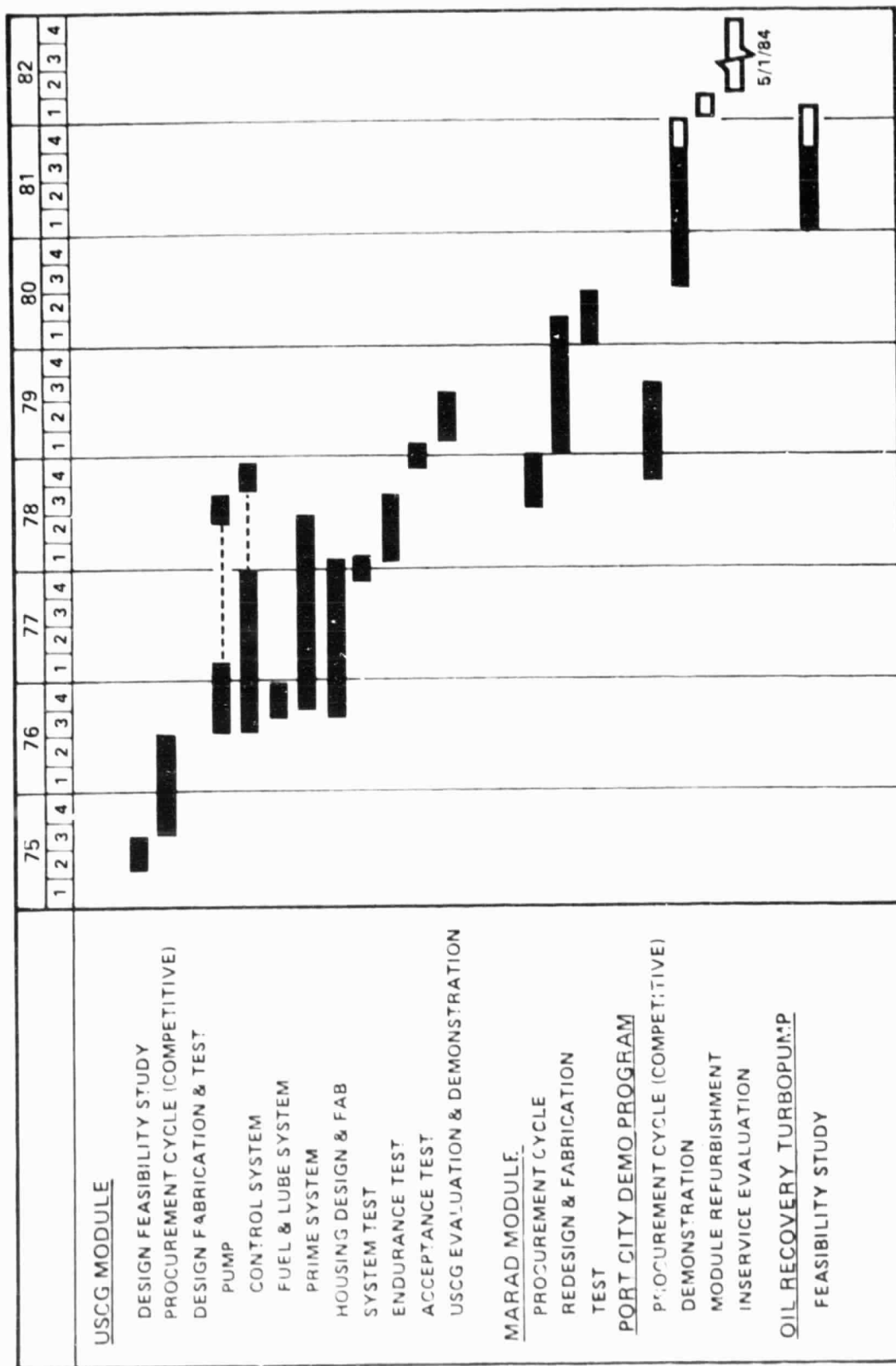


Figure 1. Development milestone chart.

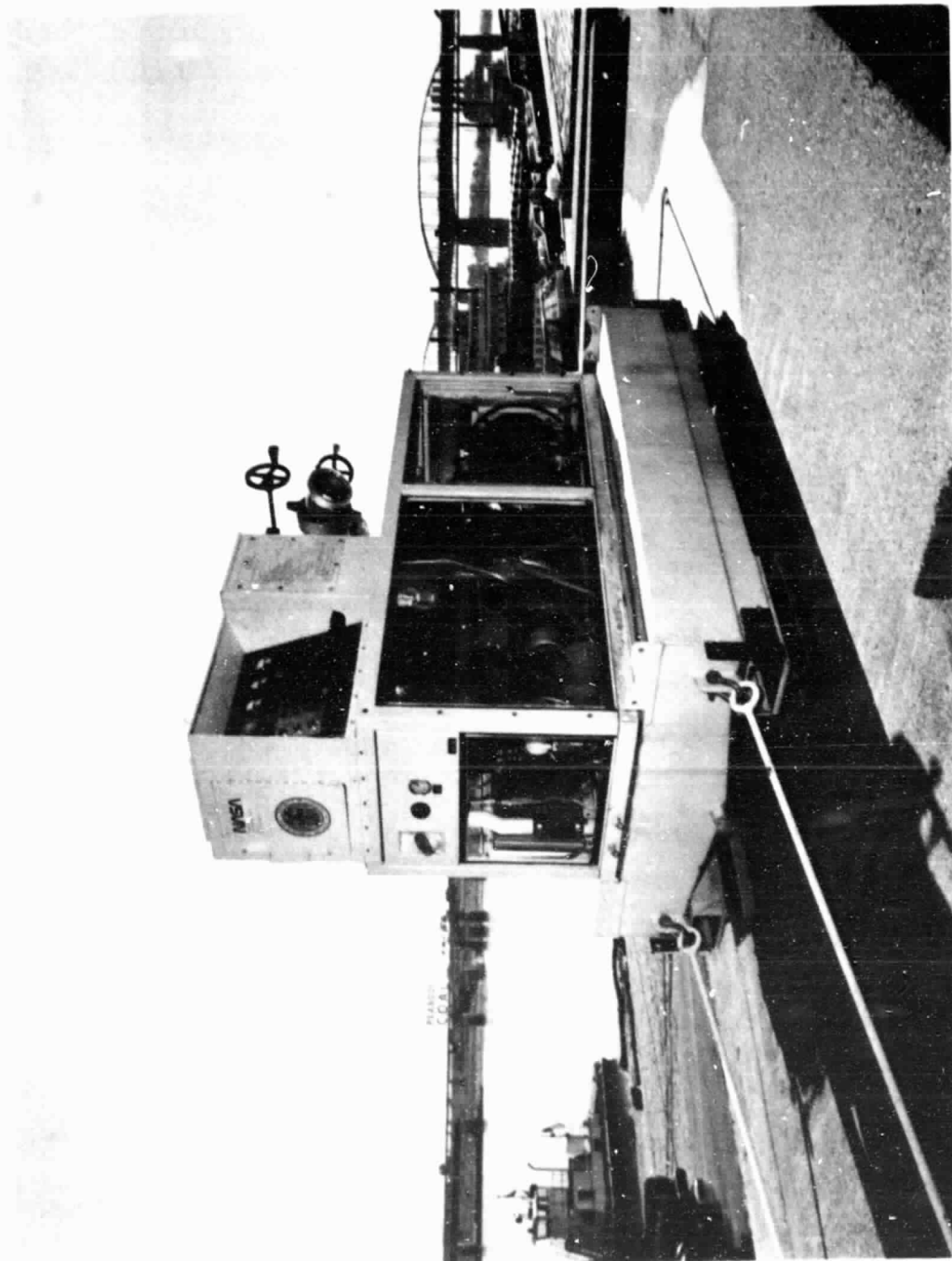


Figure 2. MARAD module. front view, panels removed.

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Figure 3. MARAD module, rear view.

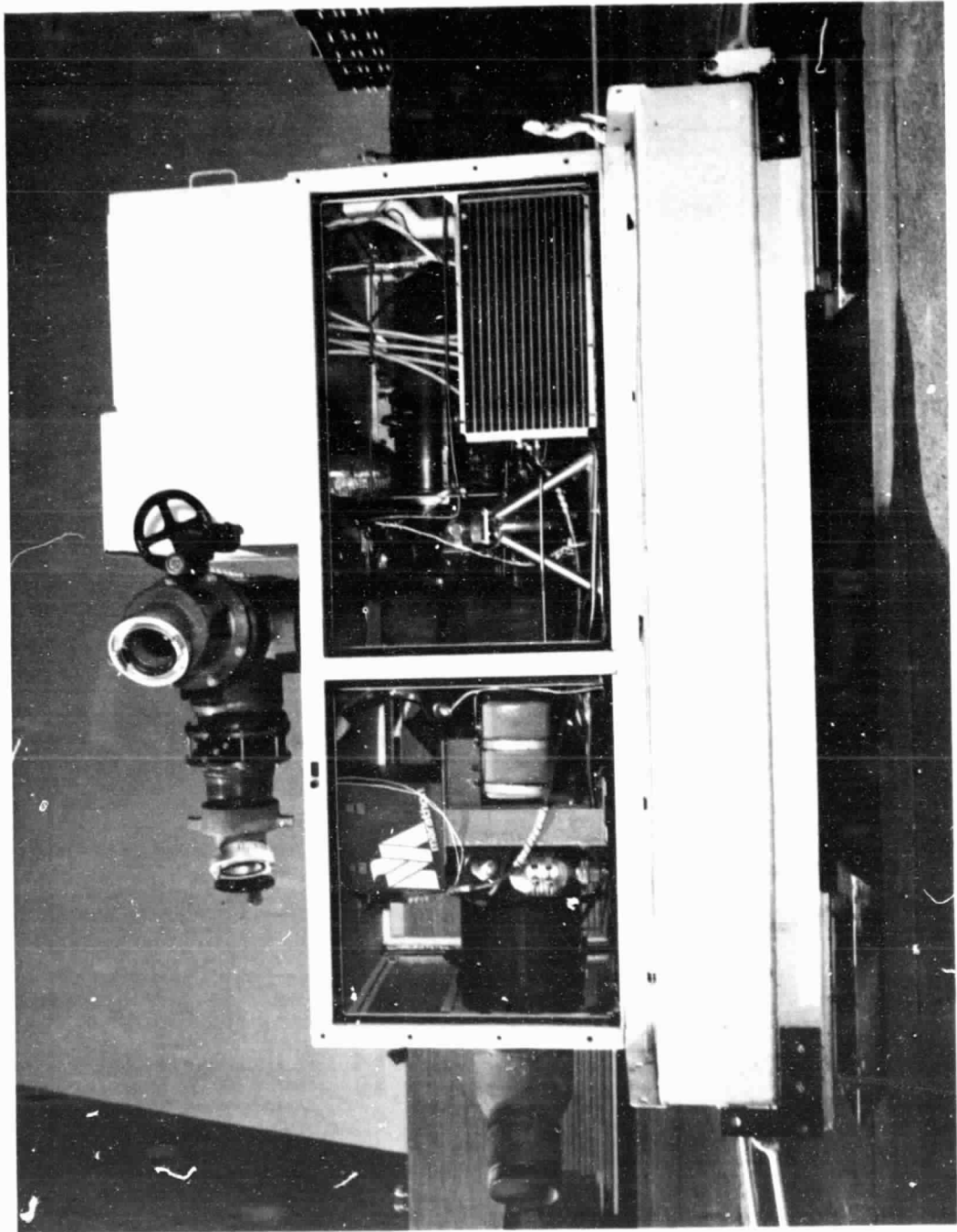


Figure 4. MARAD module, rear view, panels removed.

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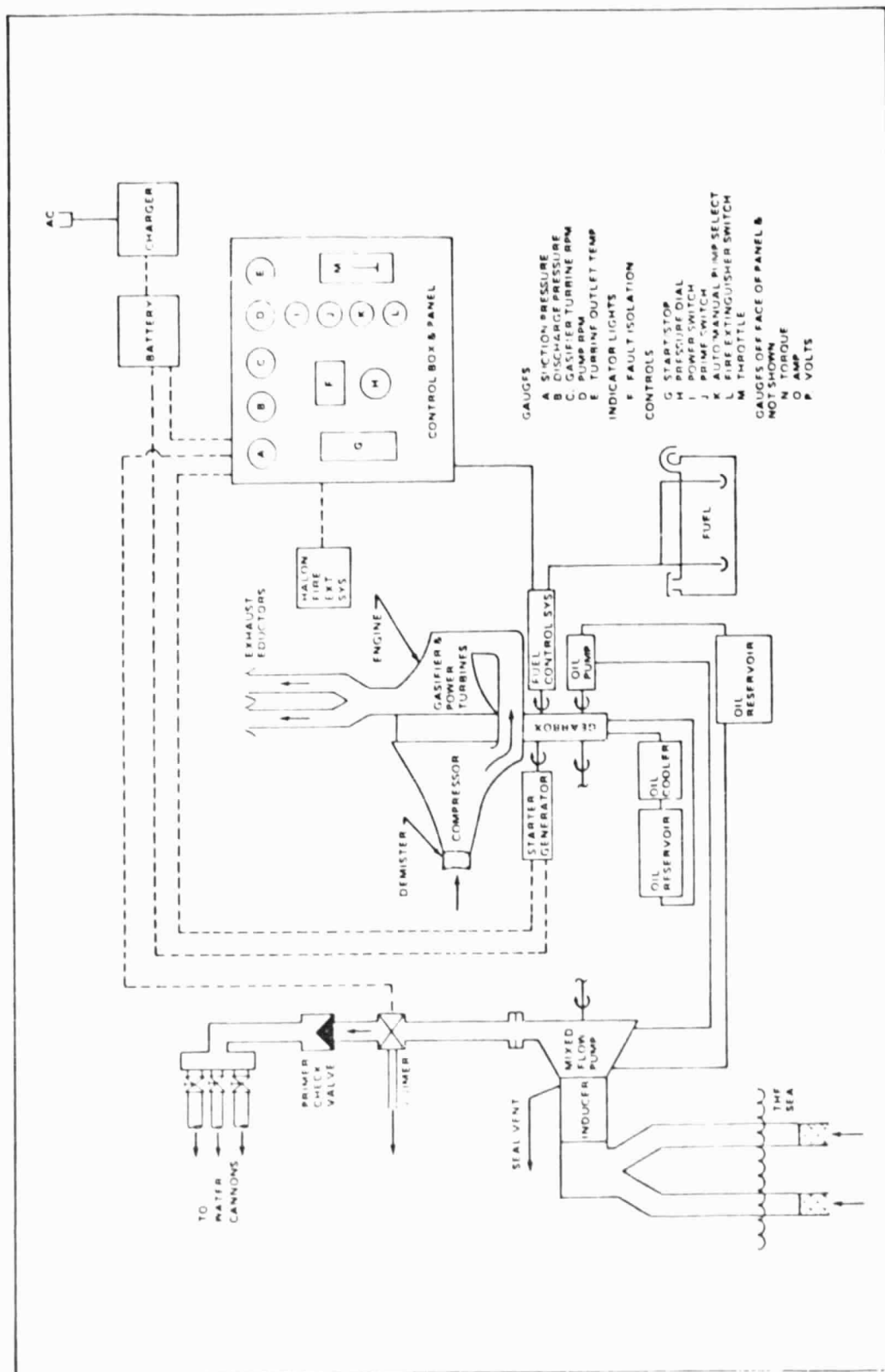


Figure 5. Module block diagram.



Figure 6. USCG module on USCG boat.



Figure 7. MARAD module on St. Louis boat.

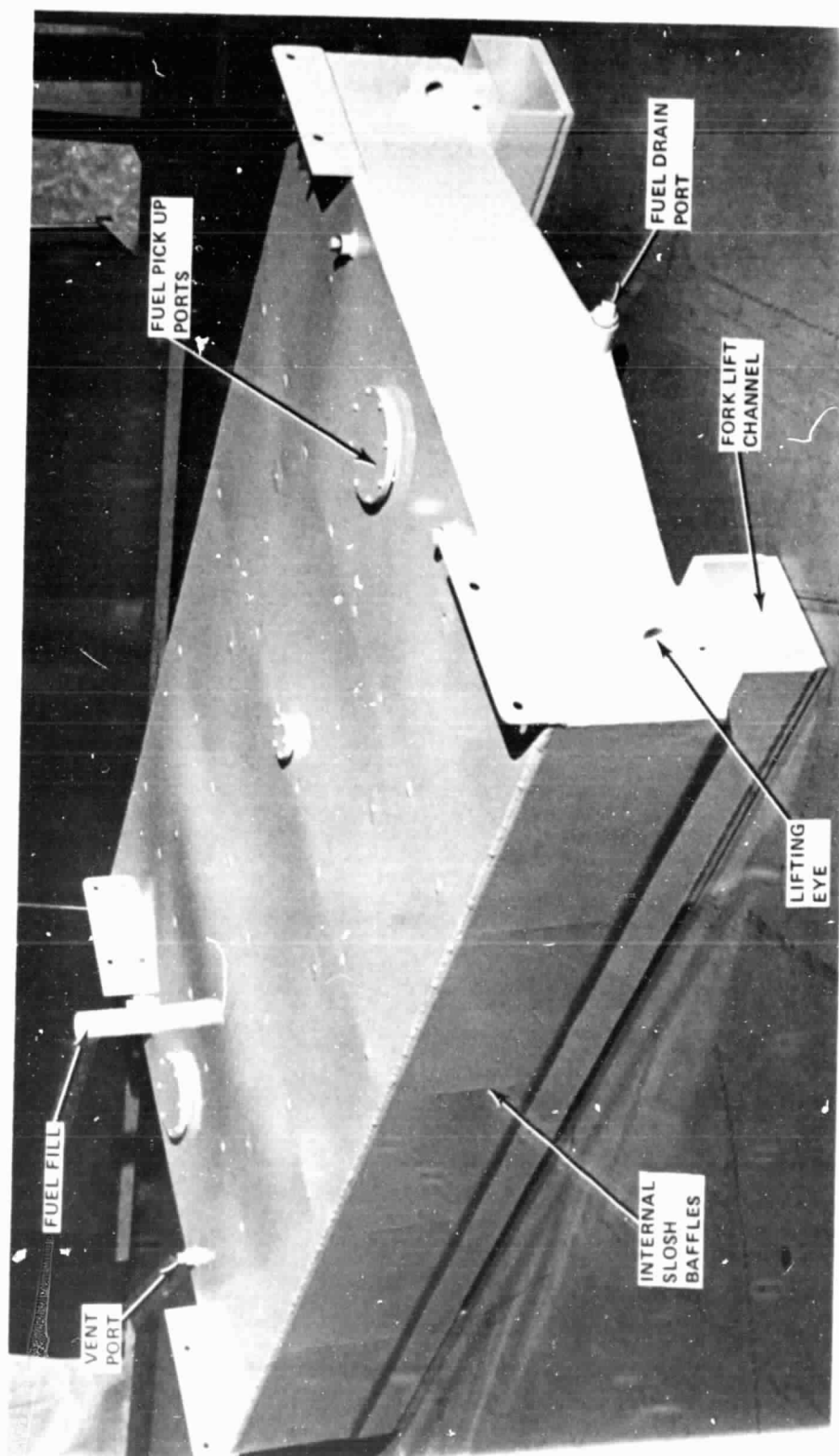


Figure 8. Fuel tank.

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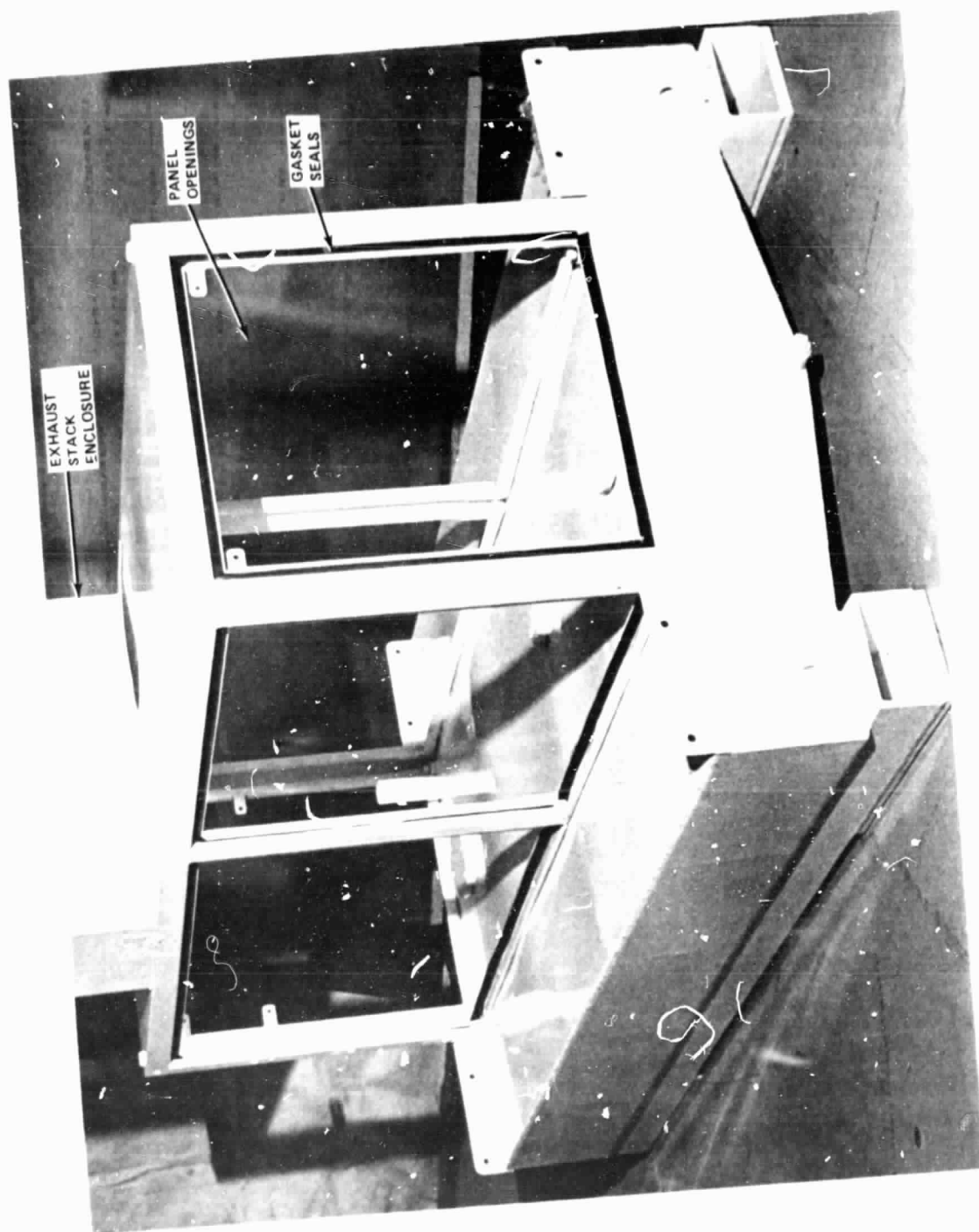


Figure 9. Support frame on fuel tank.

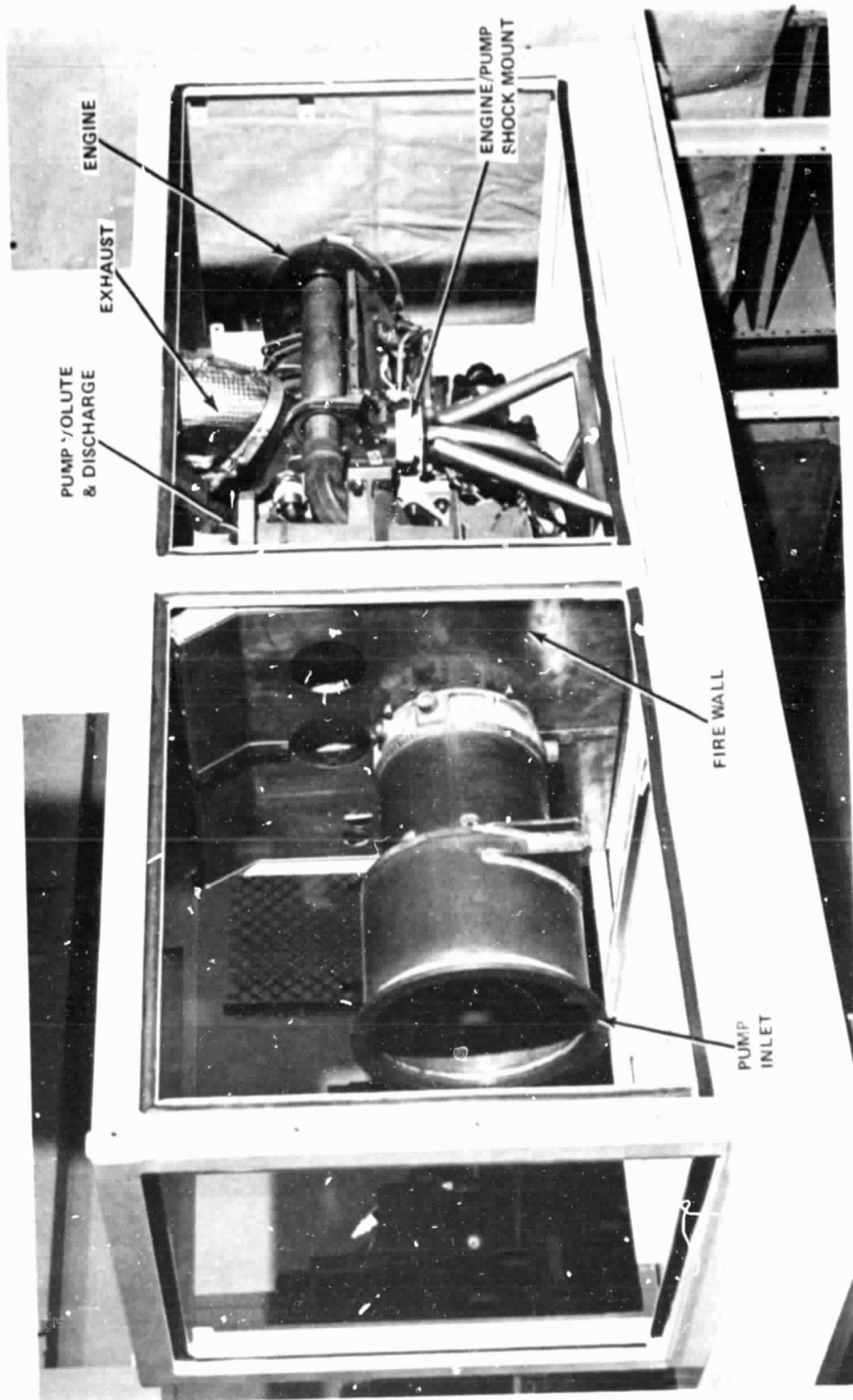


Figure 10. Engine/pump mounted to support frame.

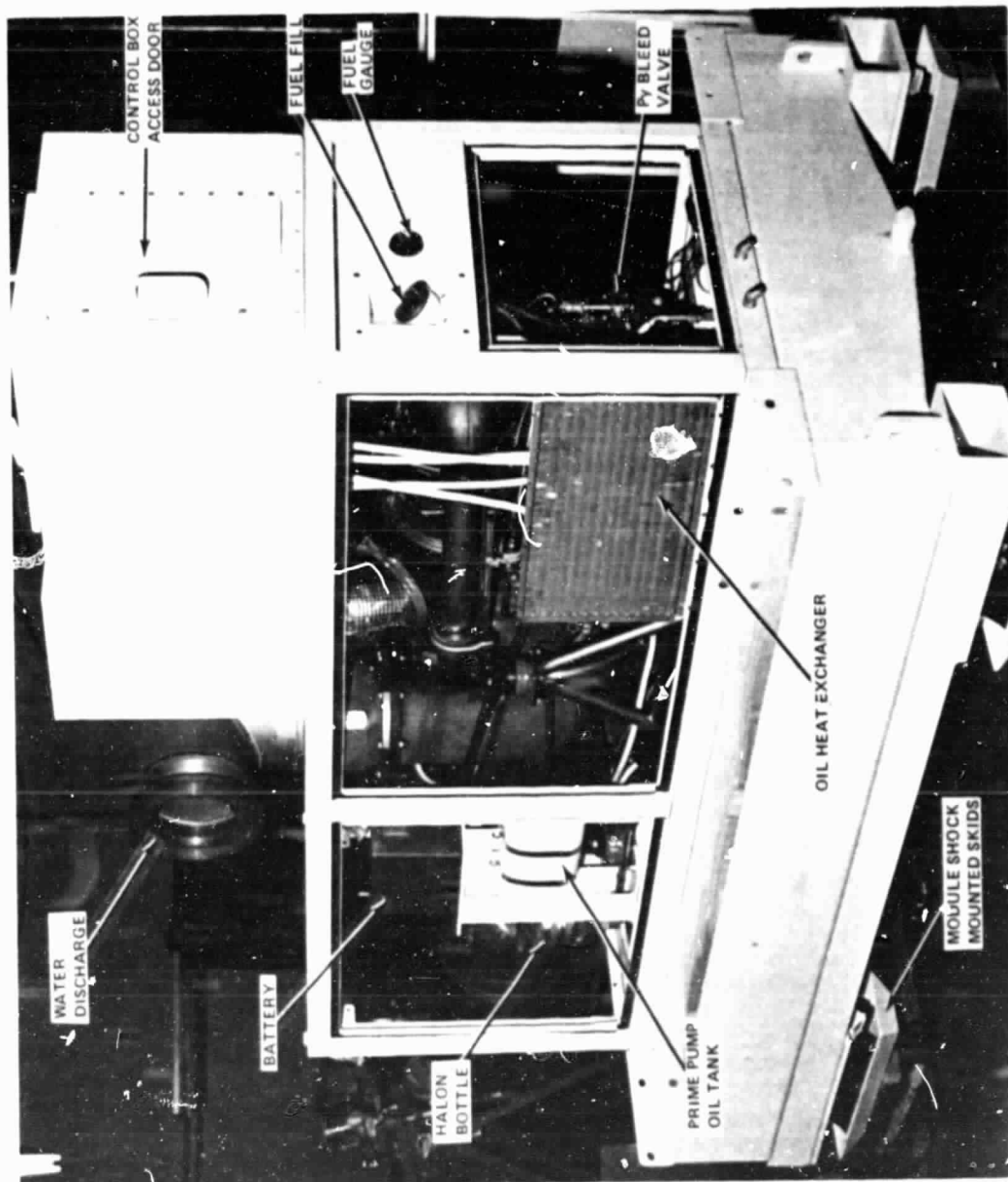


Figure 11. Module, rear view, with major components installed.

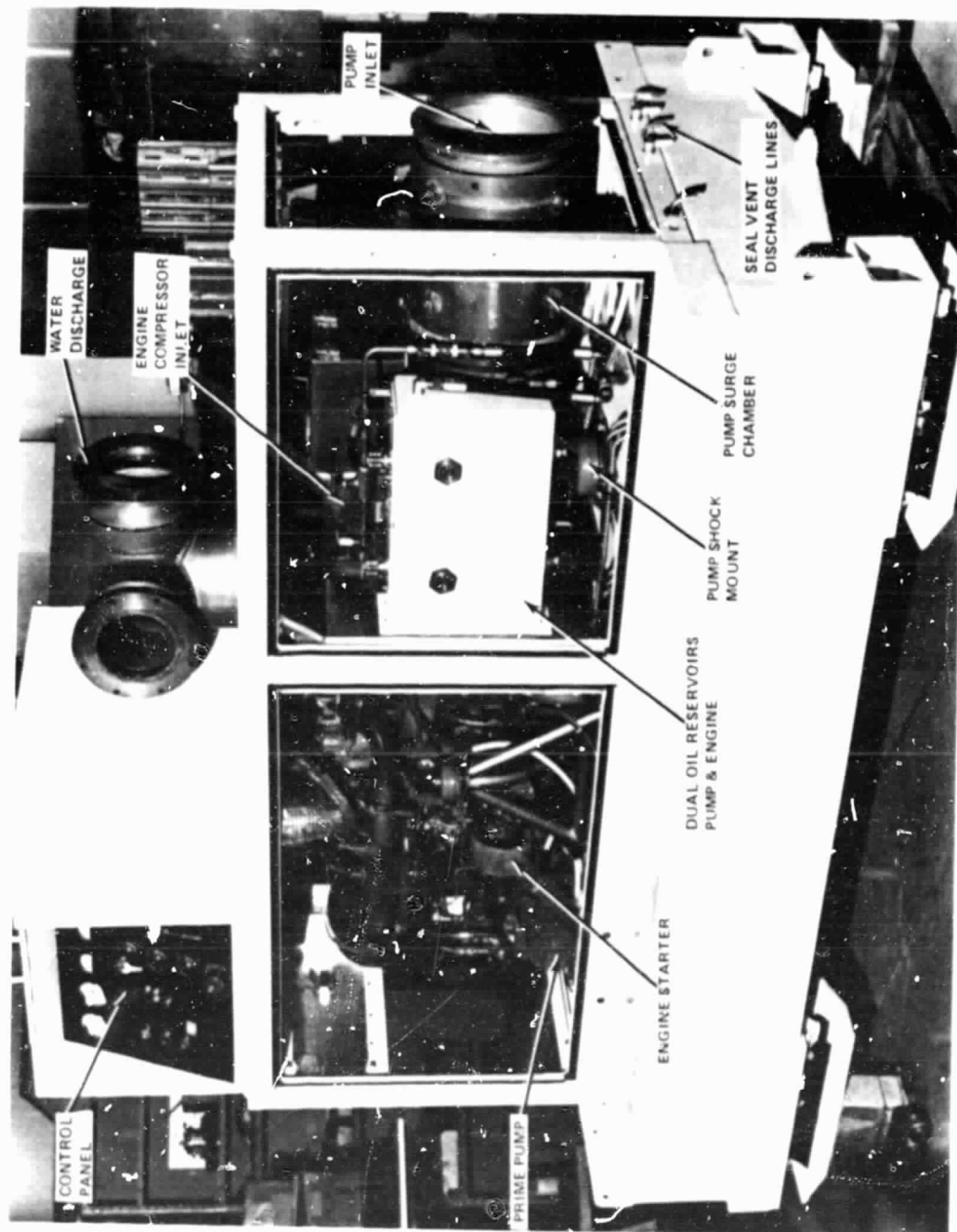


Figure 12. Module, front view, with major components installed.

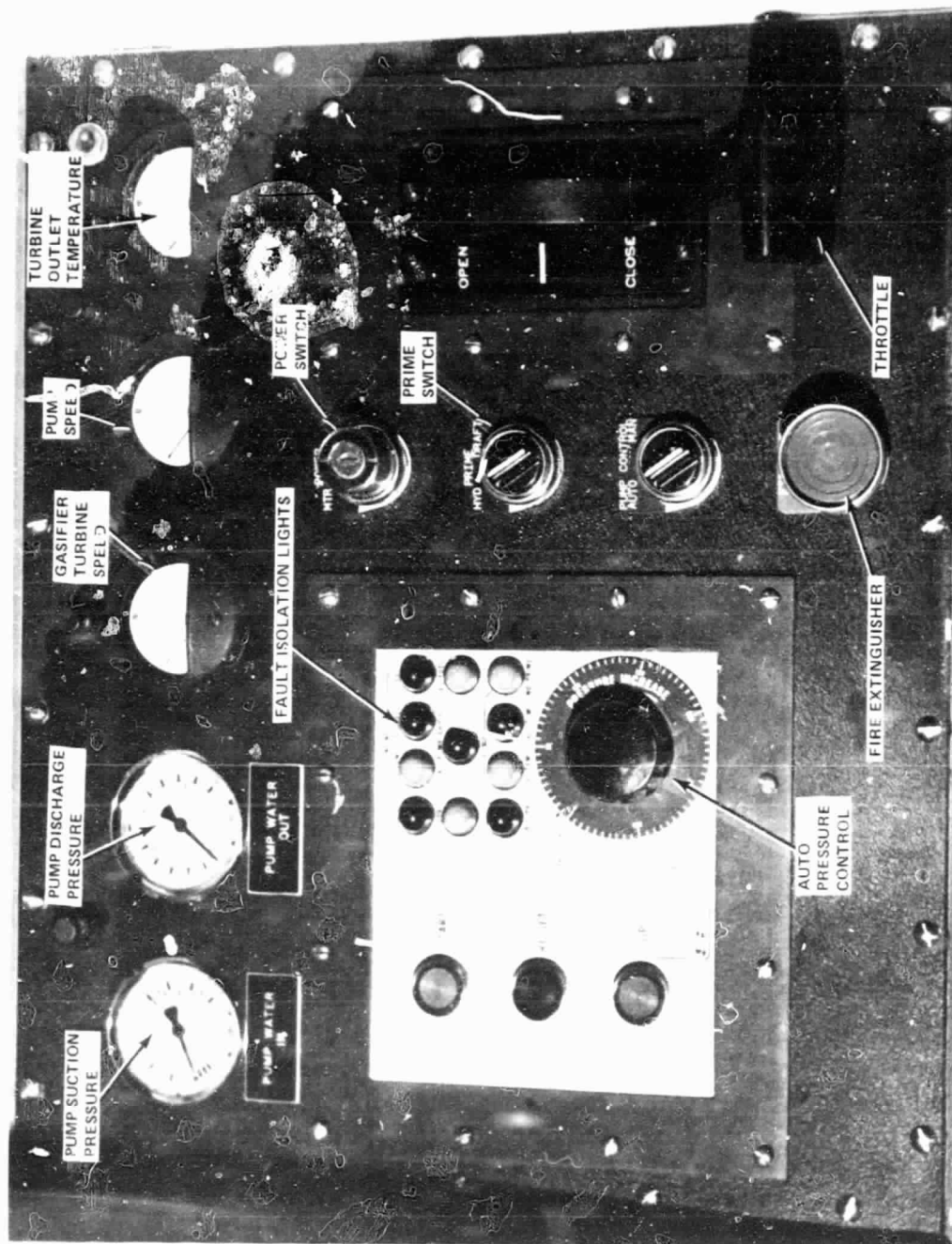


Figure 13. Control panel.

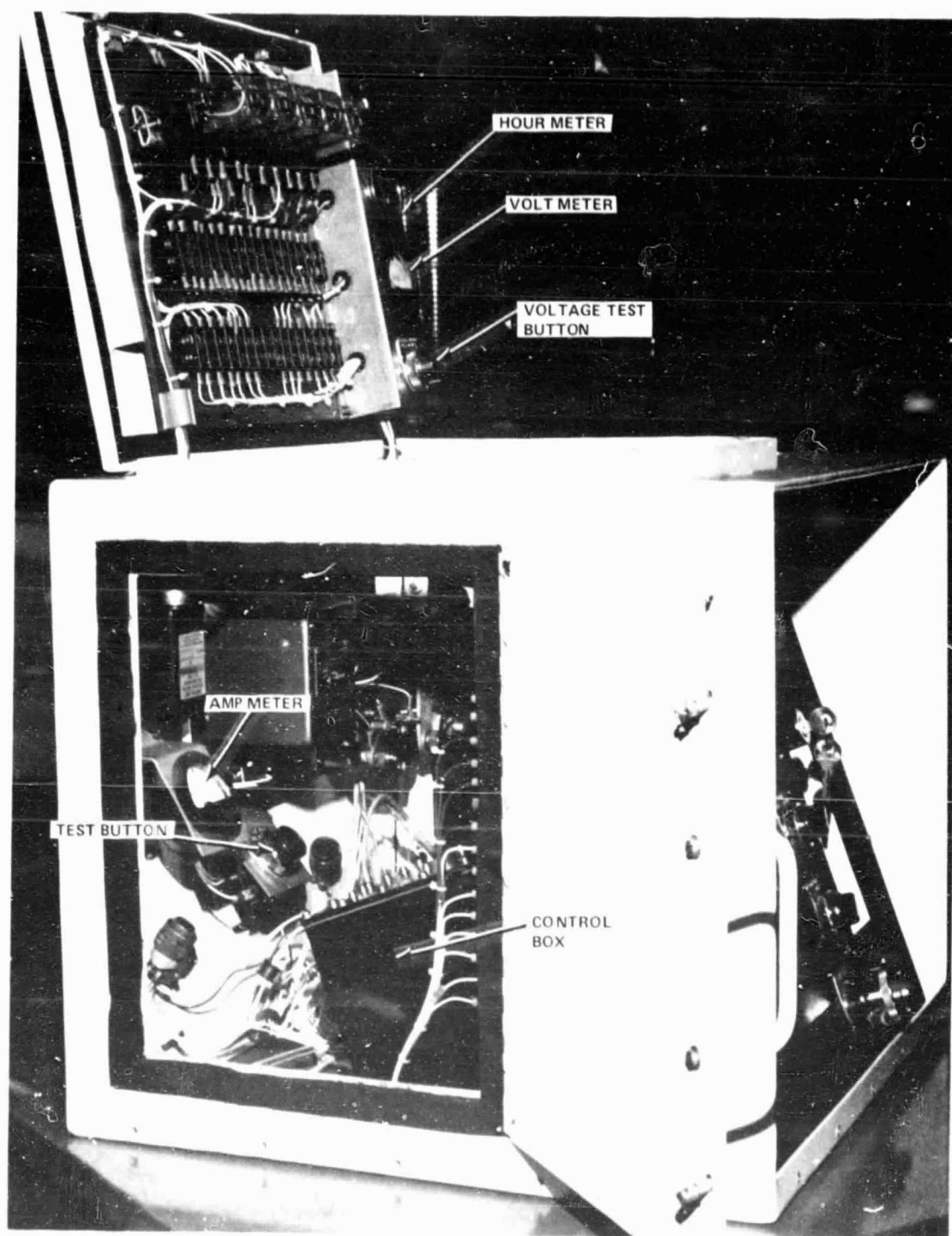


Figure 14. Control box.

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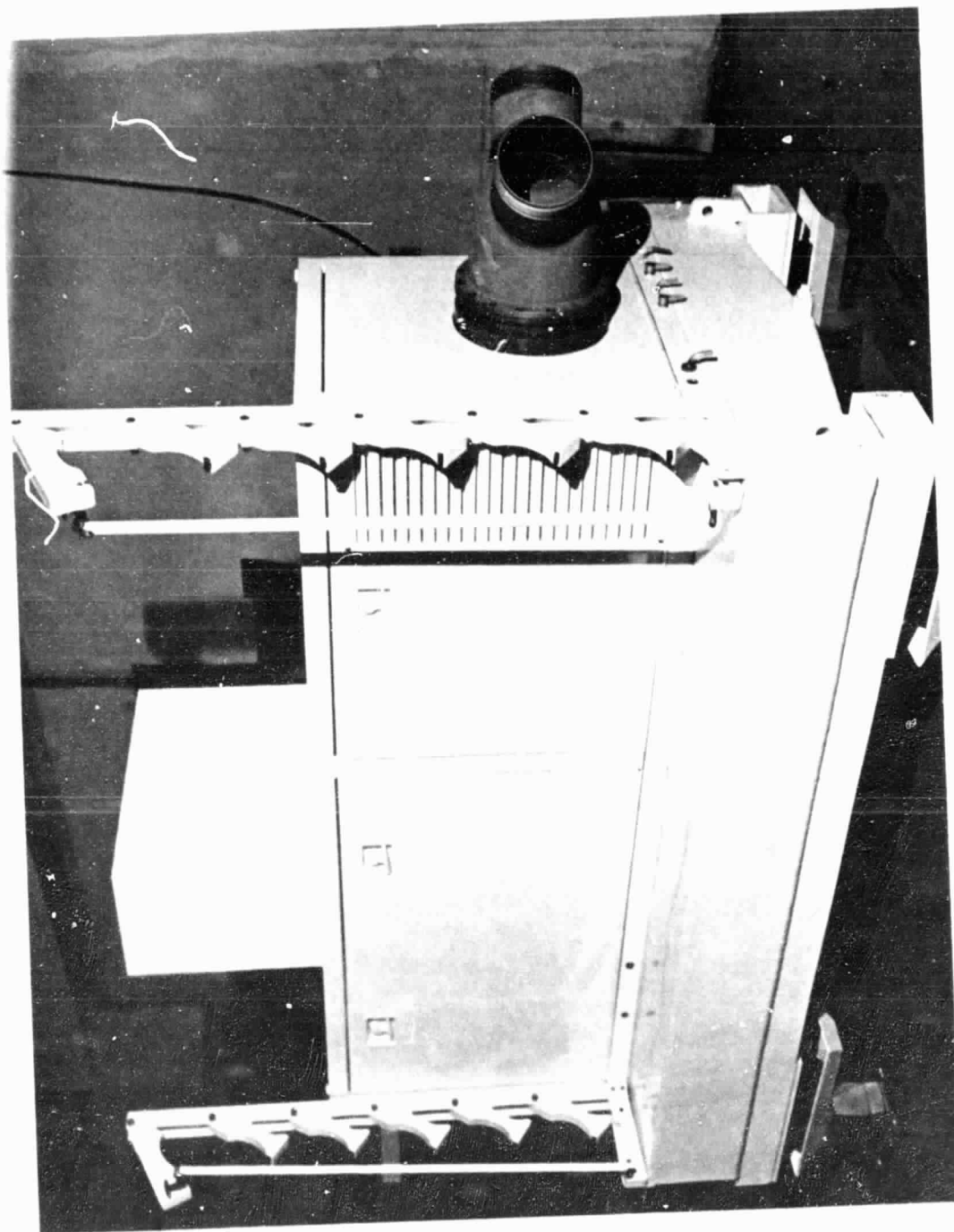


Figure 15. Module with suction hose rack.

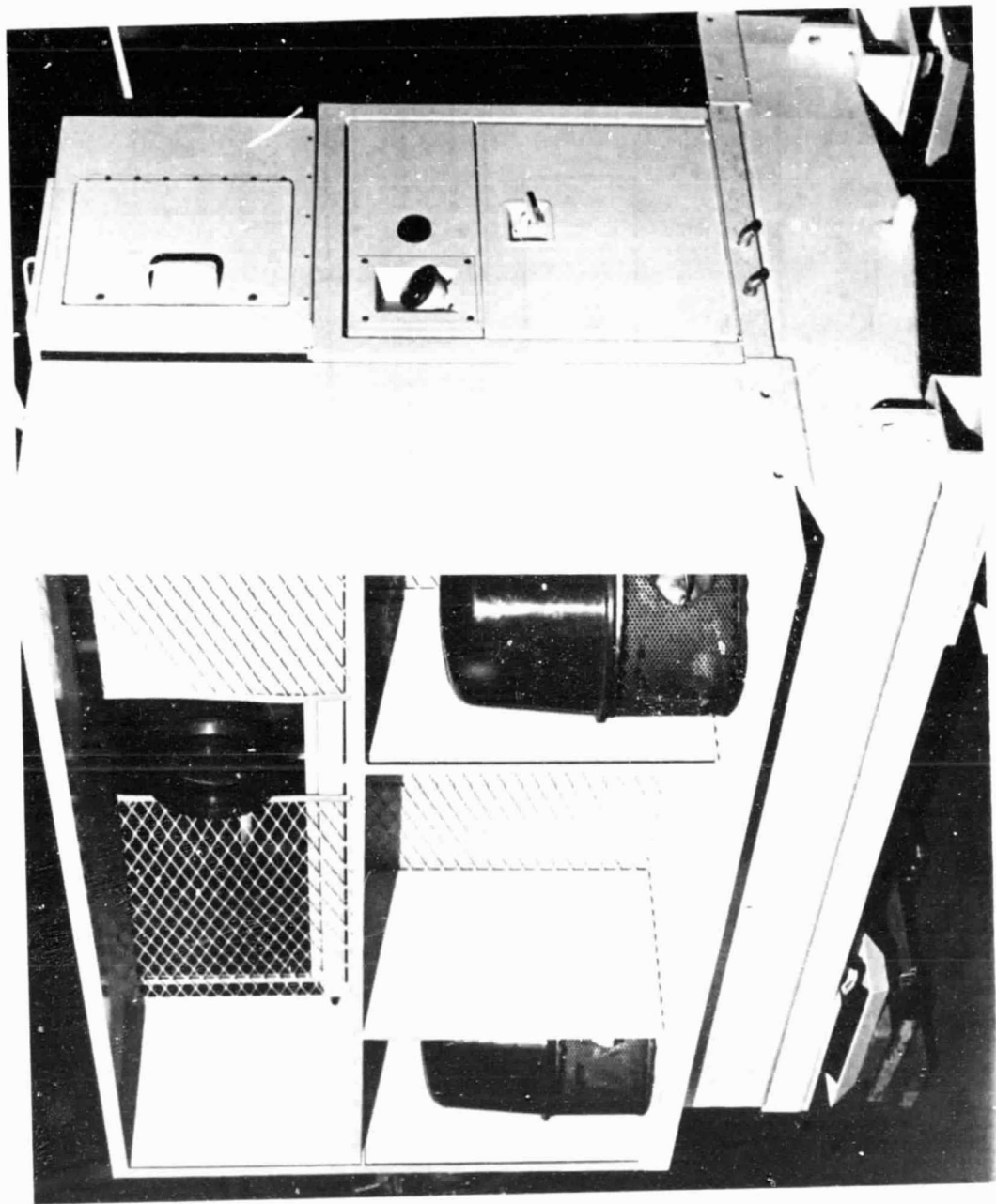


Figure 16. Module with equipment rack.

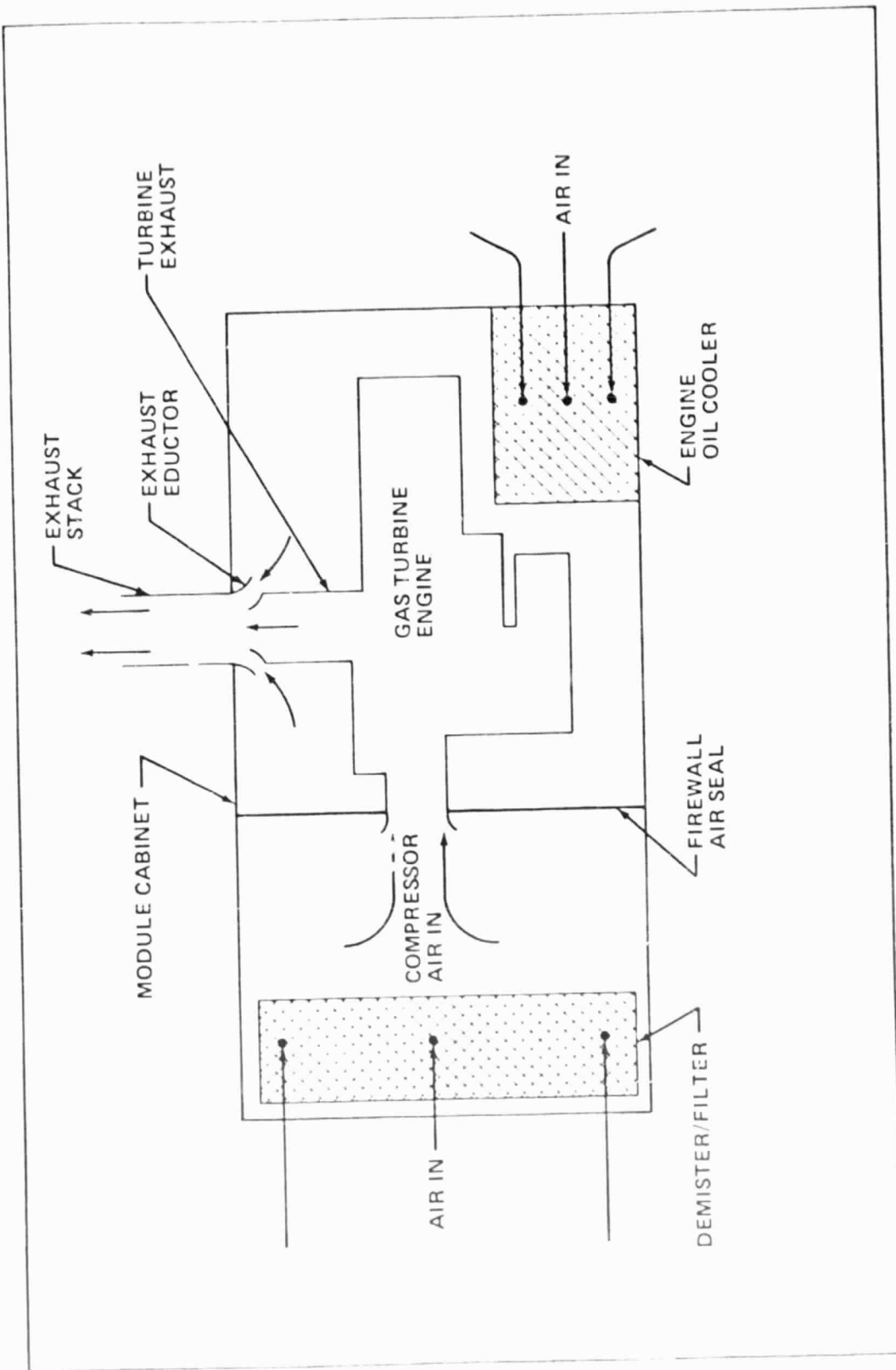


Figure 17. Air flow schematic.

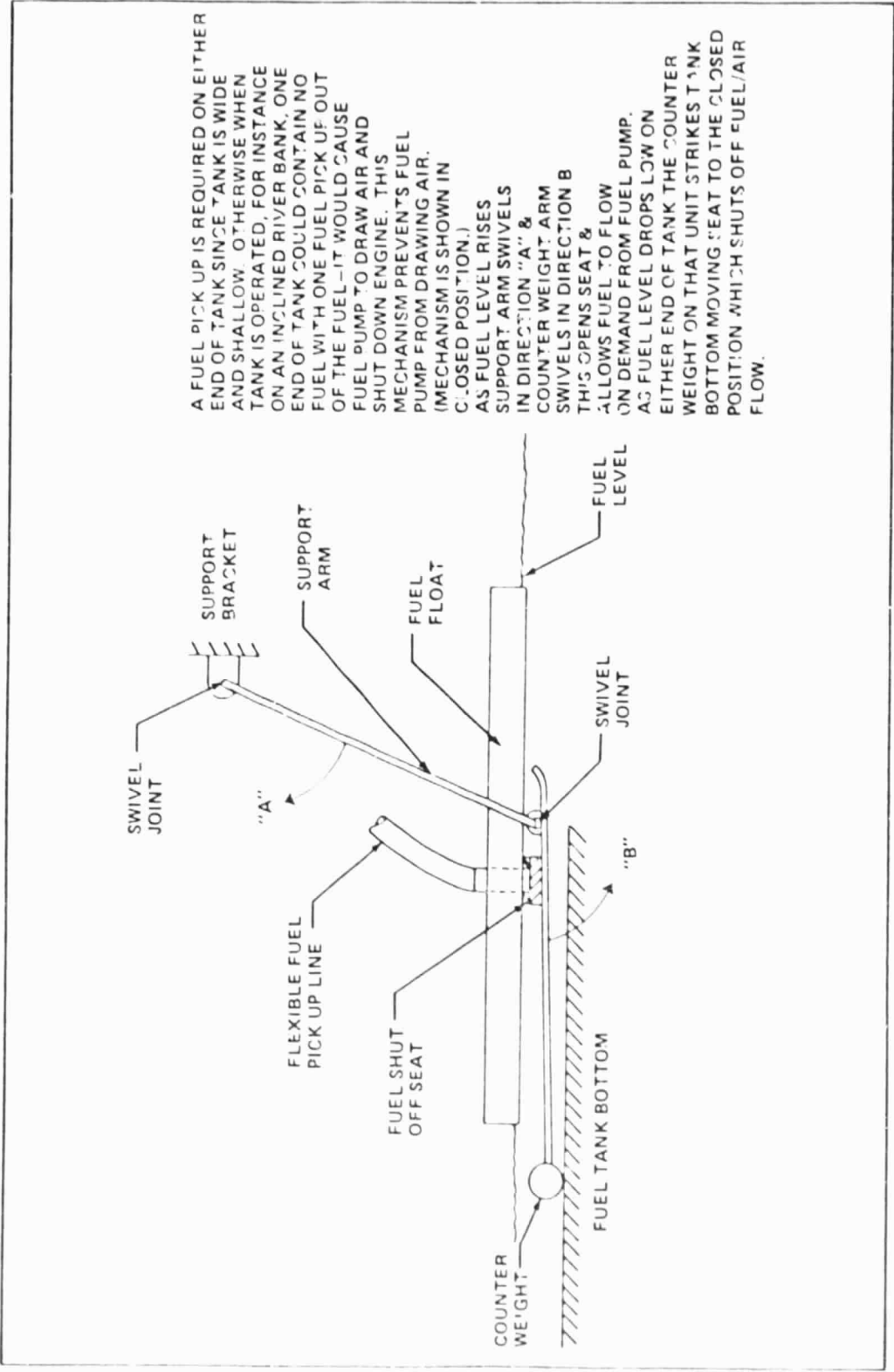


Figure 18. Fuel pickup schematic.

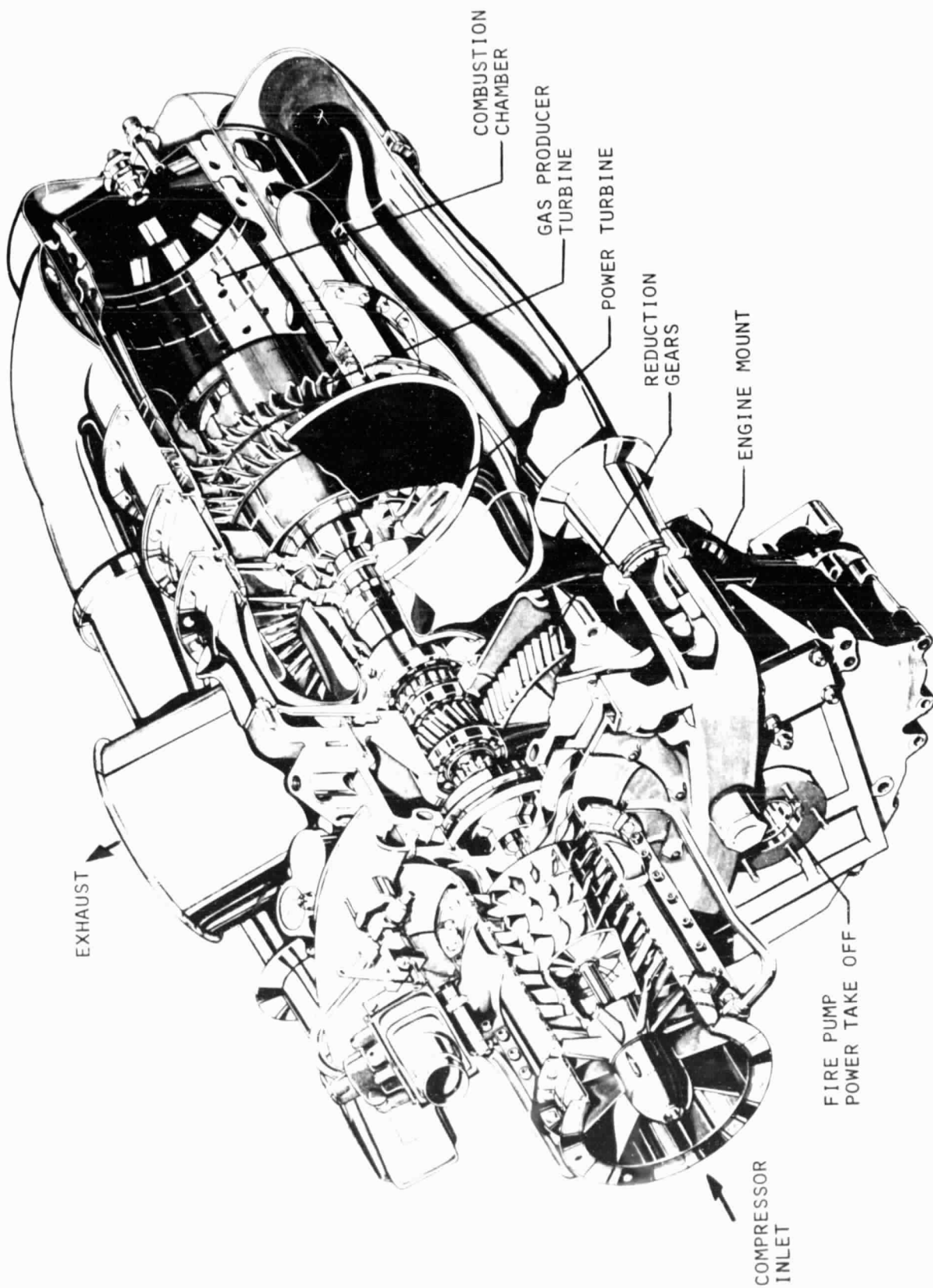


Figure 19. Engine schematic.

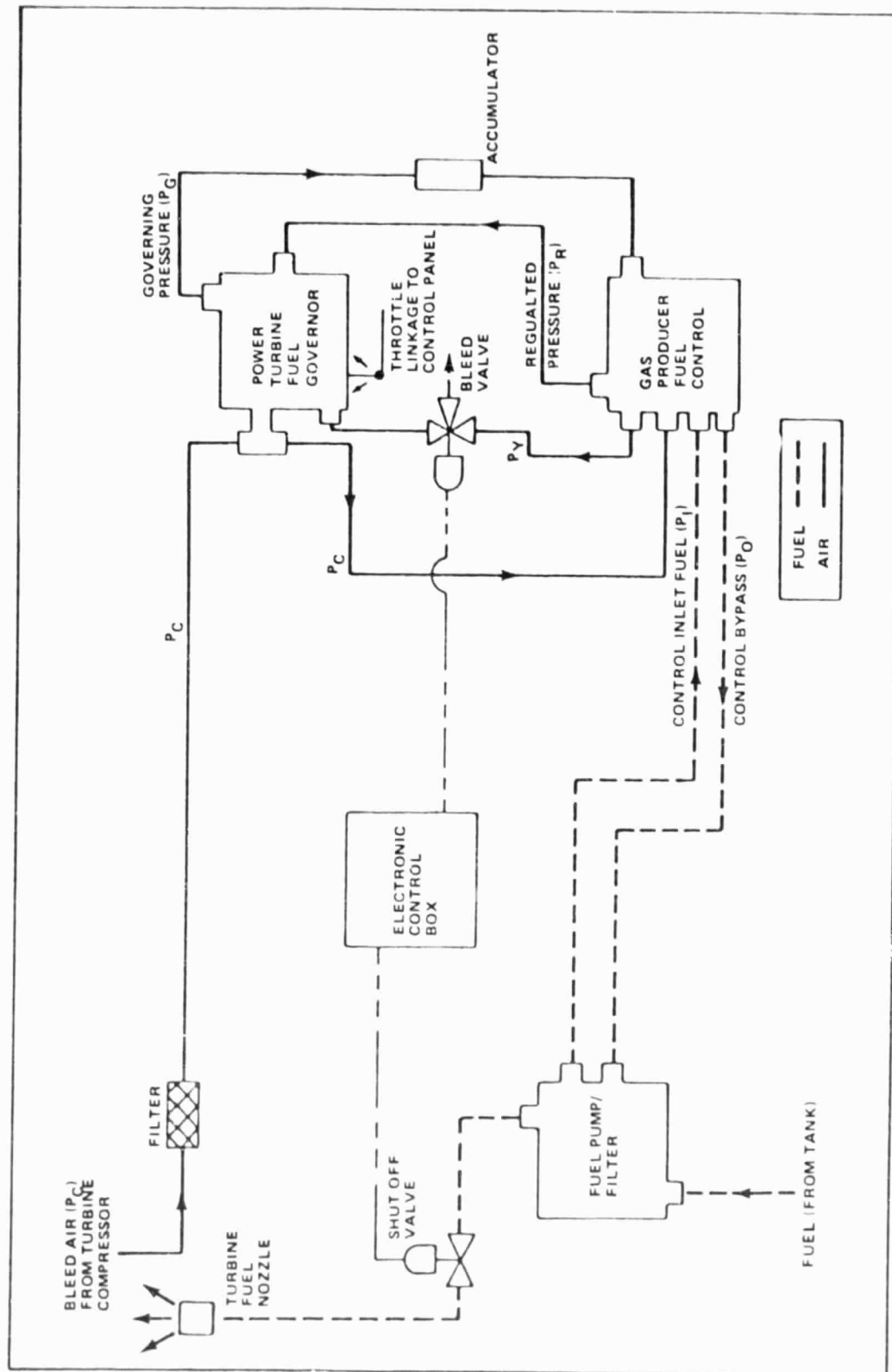


Figure 20. Control system schematic.

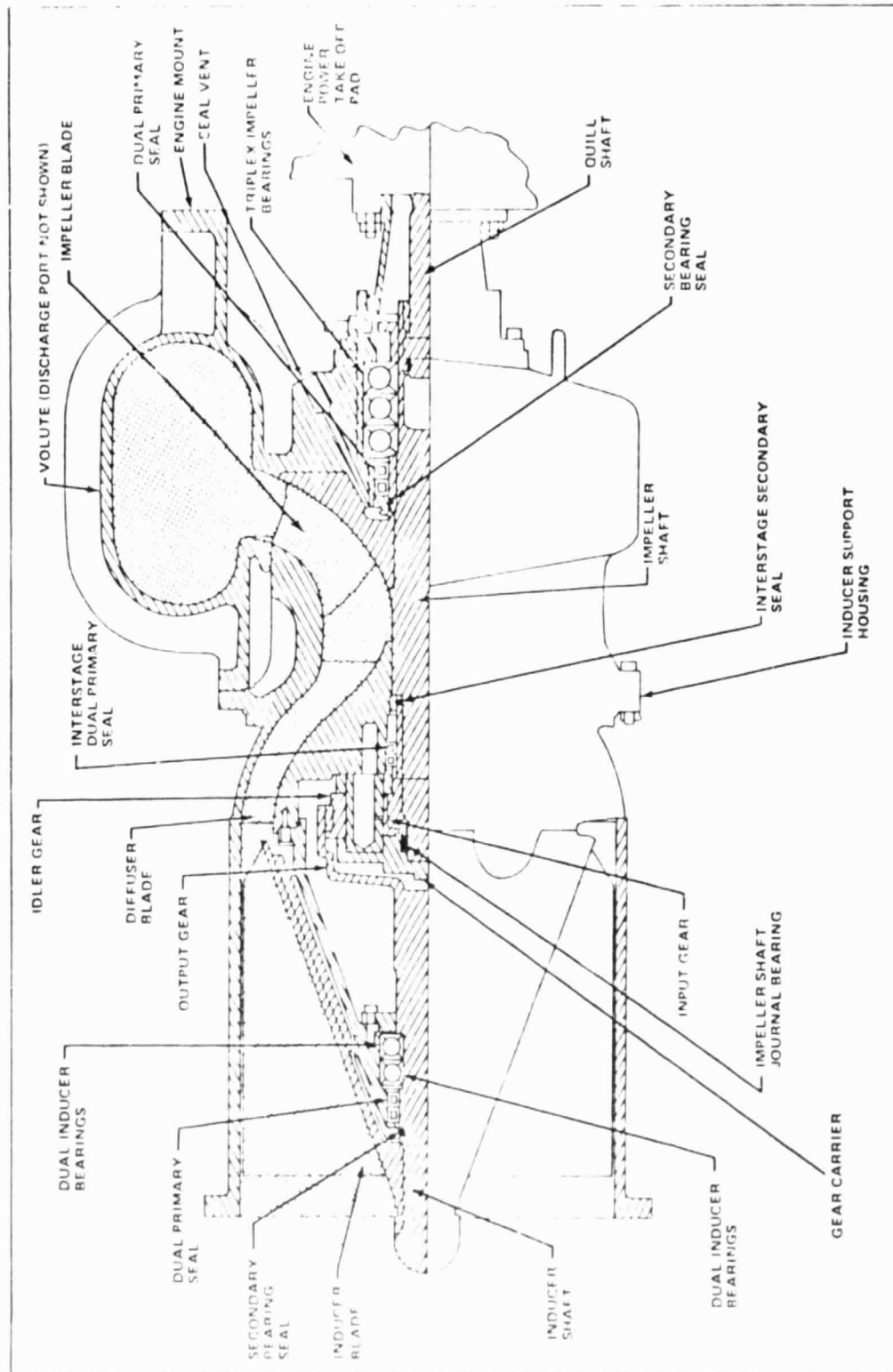


Figure 21. Pump cut away.



Figure 22. Pump gearbox.

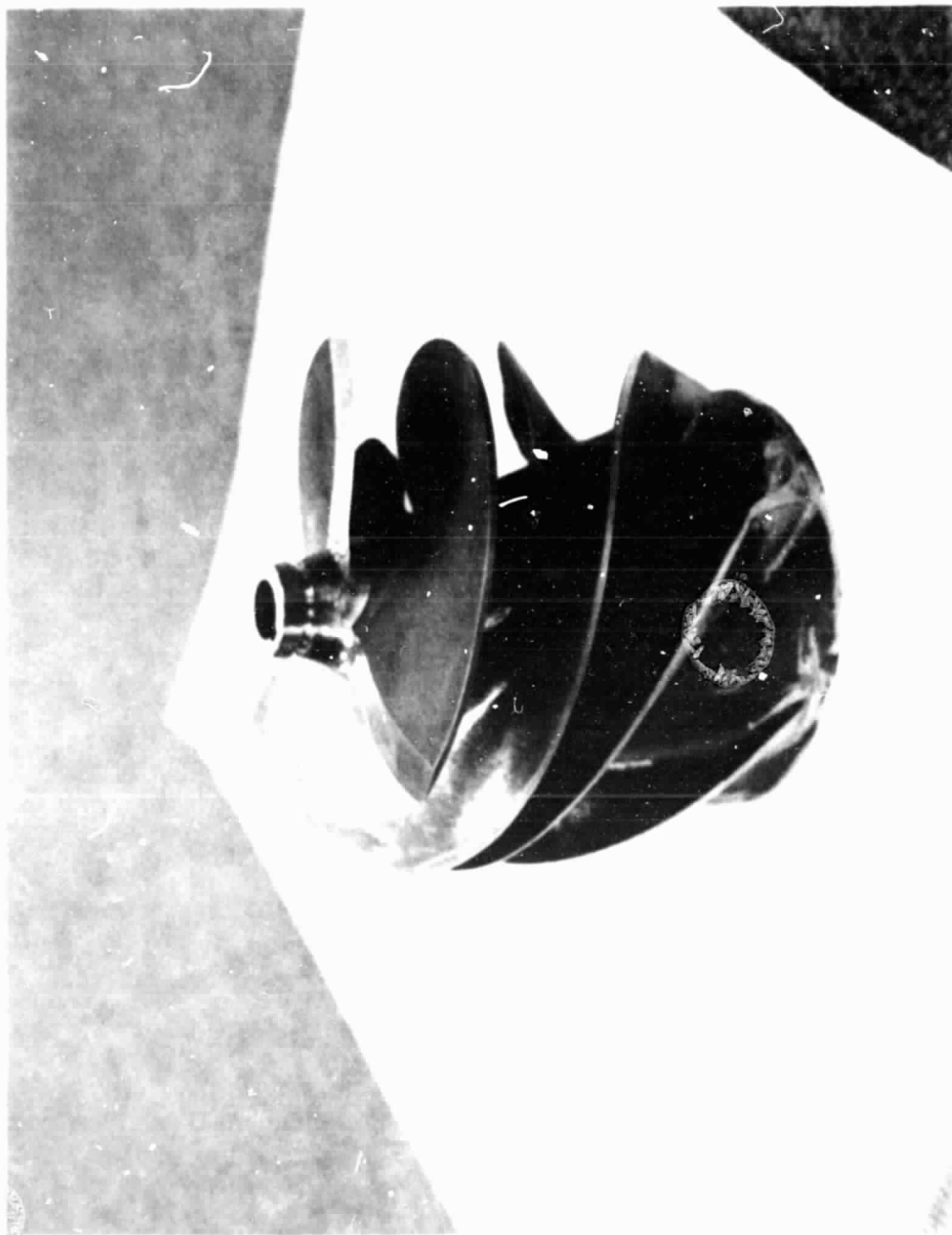


Figure 23. Inducer.



Figure 24. Impeller and shaft.

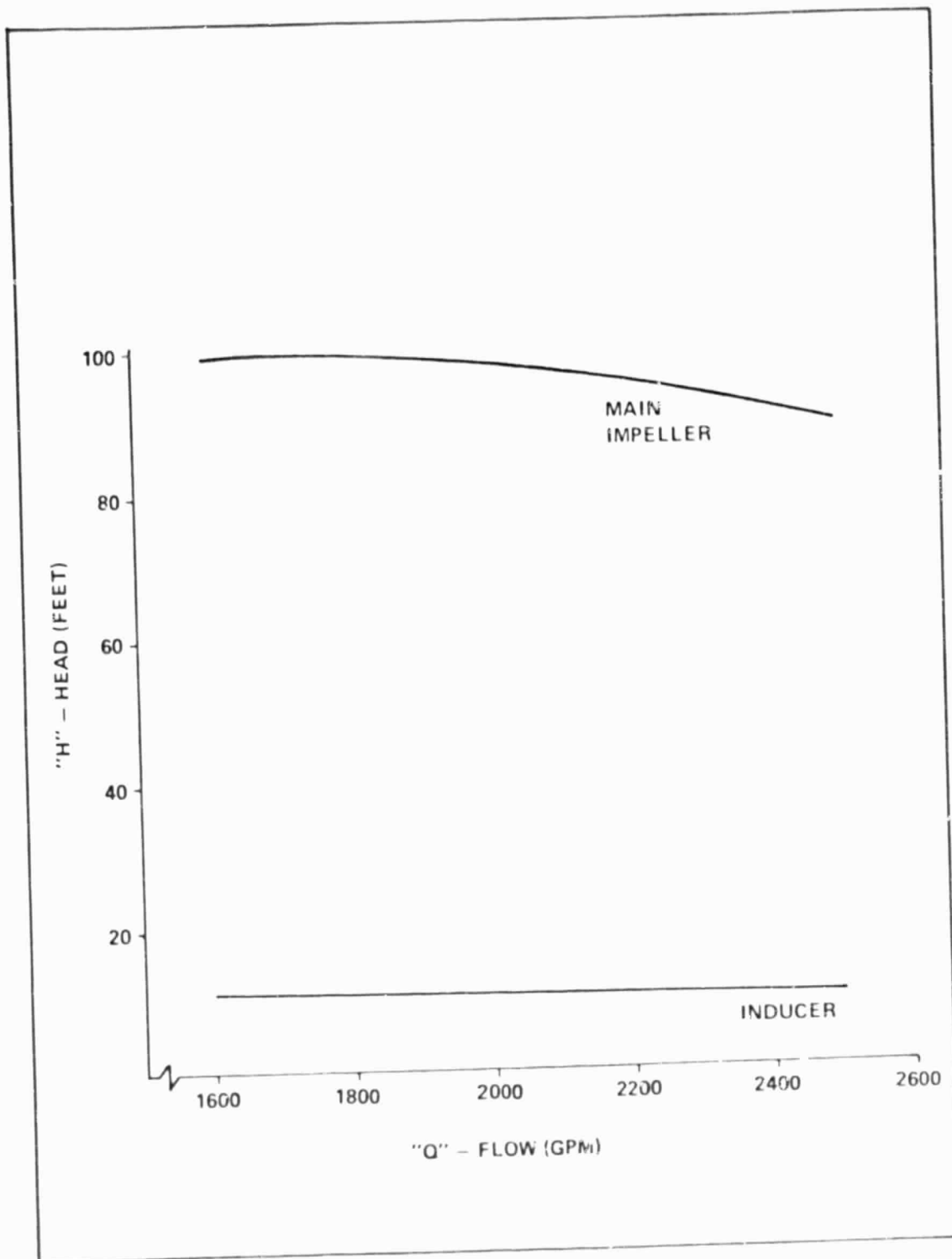


Figure 25. Impeller net positive suction head available NPSHA.

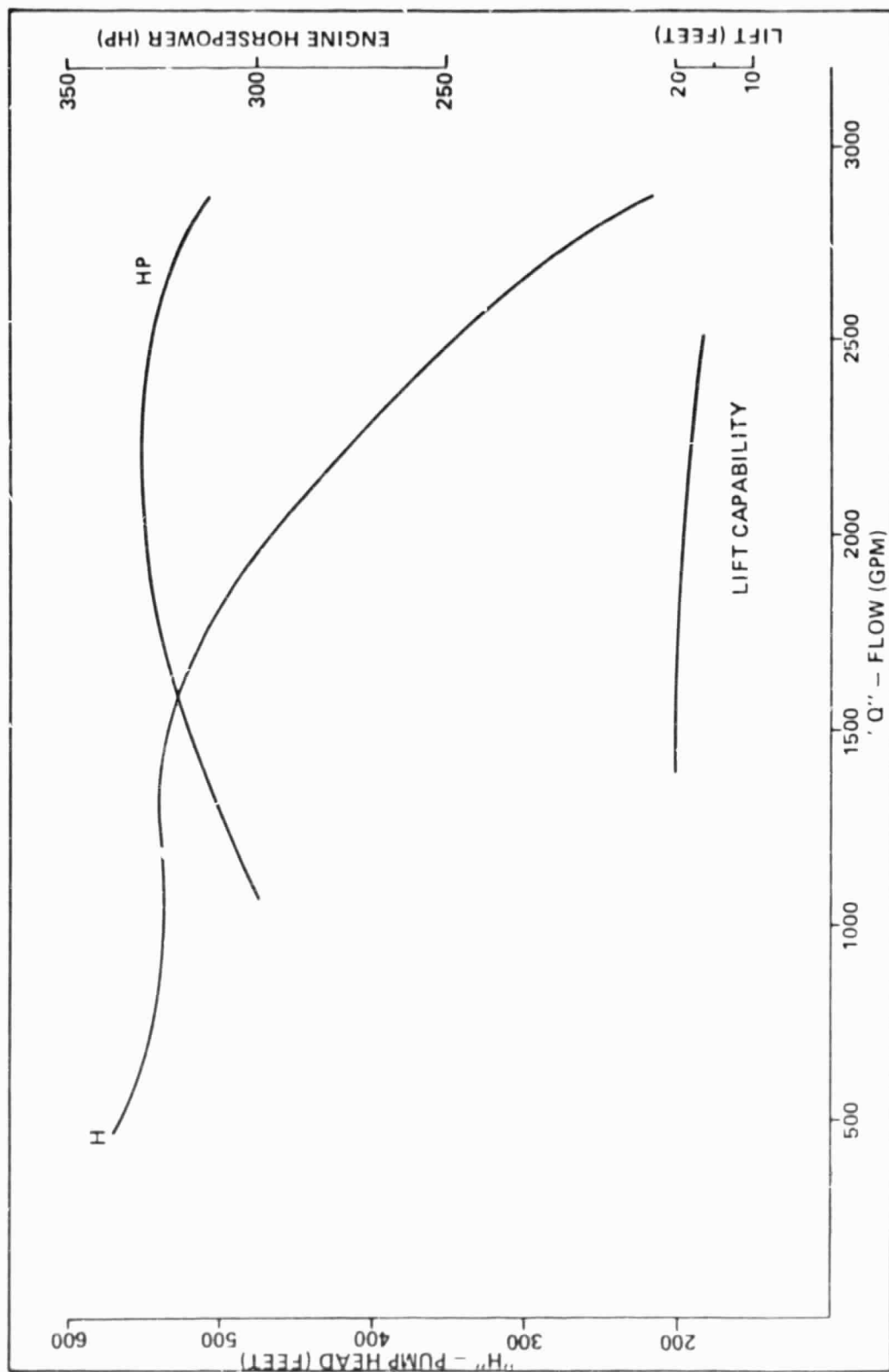


Figure 26. Pump H/Q curve.

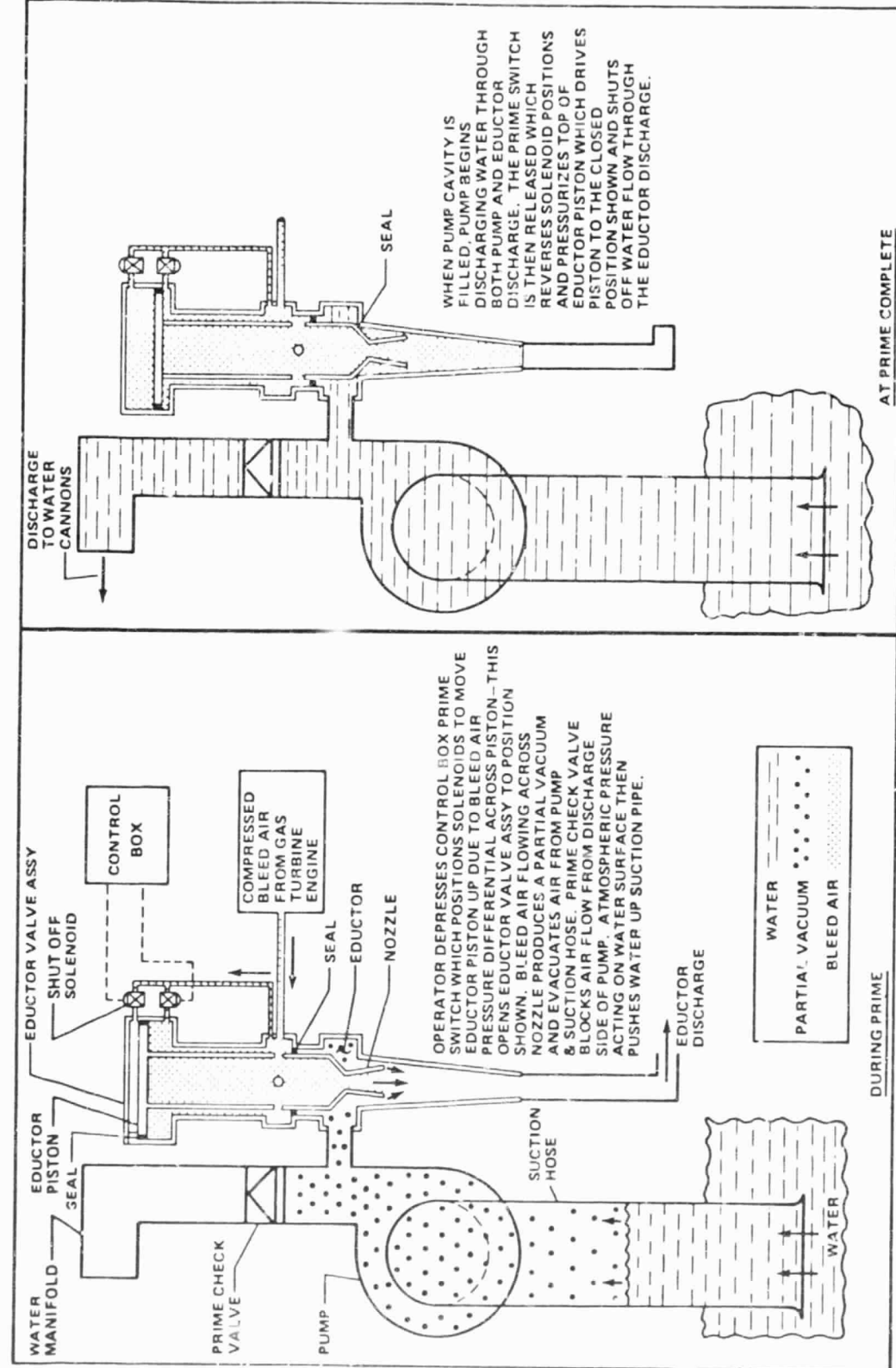


Figure 27. Eductor prime system schematic.

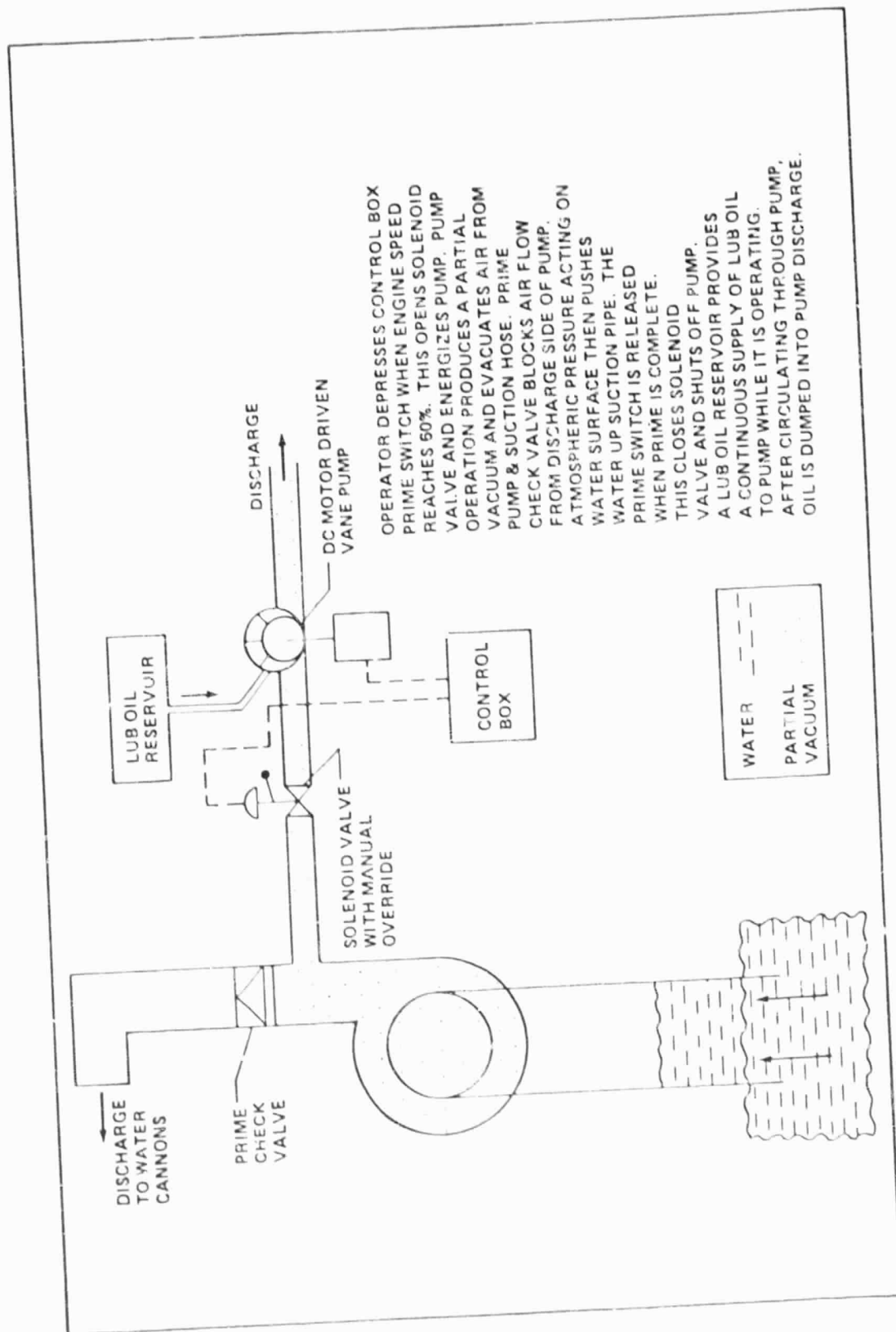


Figure 28. Pump prime system schematic.

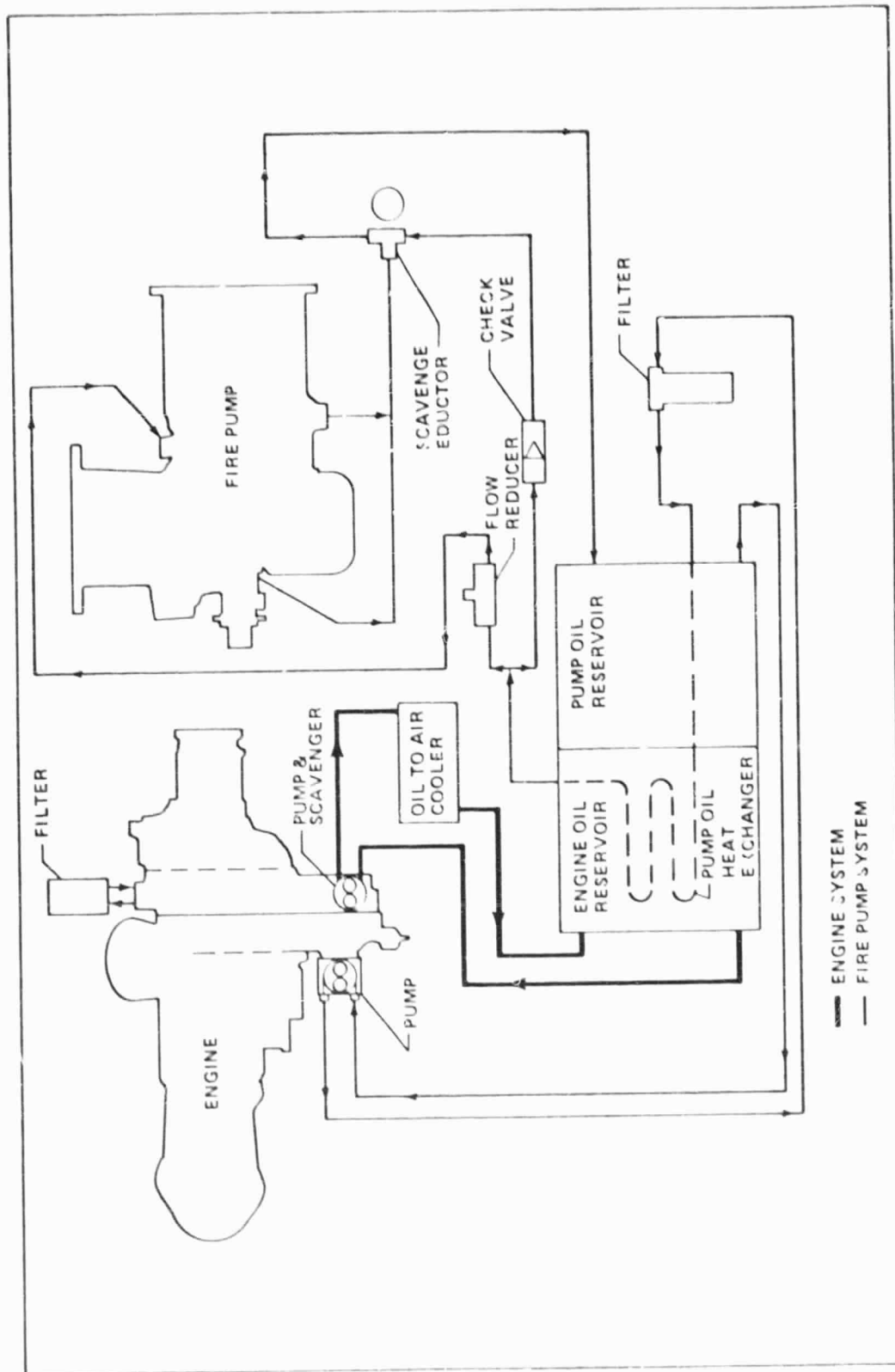


Figure 29. Lubrication schematic.

CONTROLS LOCATED ON INSTRUMENT PANEL		GAUGES LOCATED ON INSTRUMENT PANEL	
CONTROL	FUNCTION	GAUGE	DESCRIPTION
POWER SWITCH WITH KEY	ENGINE CAN BE ROTATED WITHOUT STARTING OR IT CAN BE SWITCHED TO ON FOR NORMAL OPERATION OR TO OFF	PUMP INLET PRESSURE	22 INCHES Hg VACUUM TO 50 PSIG
PRIME SWITCH	SPRING LOADED SWITCH WHICH IS HELD ON DURING PRIME SEQUENCE	PUMP DISCHARGE PRESSURE	0 TO 240 PSI
PUMP CONTROL SWITCH	SWITCH CAN BE POSITIONED TO AUTO FOR AUTOMATIC PRESSURE CONTROL OR TO MANUAL FOR FLOW CONTROL BY THROTTLE POSITION	N ₁ RPM	ROTATING SPEED OF THE GASIFIER TURBINE (FULL THROTTLE ~ 100%)
THROTTLE	SETS ENGINE RPM BY LINKAGE TO GOVERNOR WHICH IN TURN METERS FUEL FLOW	N ₂ RPM	PUMP SPEED (FULL THROTTLE CONTINUOUS OF 90%)
PRESSURE ADJUSTMENT DIAL	DIAL IS USED TO SET DISCHARGE PRESSURE WHICH IS THE AUTOMATICALLY MAINTAINED	TOT	TURBINE OUTLET TEMPERATURE (FULL POWER ~ 750°C/ MAXIMUM)
START BUTTON	INITIATES MODULE OPERATION	GAUGES NOT LOCATED ON INSTRUMENT PANEL	
RE SET BUTTON	PRESSING RE SET TURNS OFF ANY FAULT ISOLATION LIGHTS WHICH MAY BE ILLUMINATED		
STOP BUTTON	USED FOR EMERGENCY MODULE SHUT DOWN		
FIRE EXTINGUISHER BUTTON	USED TO MANUALLY DISCHARGE HALON SYSTEM IN CASE OF FIRE		
PANEL LIGHT SWITCH	TOGGLE SWITCH TO ILLUMINATE VIEWING LIGHTS LOCATED ON PANEL		
CONTROLS NOT LOCATED ON INSTRUMENT PANEL		GAUGES NOT LOCATED ON INSTRUMENT PANEL	
CONTROL	FUNCTION	GAUGE	DESCRIPTION
DISCHARGE VALVES	CRANK OPERATED SHUT OFF VALVES ARE LOCATED IN EACH OF THREE DISCHARGE LINES. VALVES ARE SET TO GIVE SELECTED FLOW DISTRIBUTION	VOLT METER & BUTTON (SEE FIGURE 14)	BY MOTORING OVER ENGINE AND DEPRESSING BUTTON THE BATTERY CHARGE CONDITION CAN BE DETERMINED
DRAIN VALVES	PUMP CAVITY CAN BE DRAINED BY OPENING DRAIN VALVES	AMP METER (SEE FIGURE 14)	INDICATES OUTPUT RATE OF GENERATOR
		FUEL GAUGE (SEE FIGURE 2)	INDICATES DIESEL FUEL LEVEL
		TORQUE METER (SEE FIGURE 2)	INDICATES ENGINE TORQUE FROM WHICH HORSEPOWER CAN BE COMPUTED
		SEE FIGURE 32 FOR FAULT ISOLATION LIGHT INDICATORS WHICH ARE LOCATED ON PANEL	

Figure 30. Table of controls and gauges.

THE FOLLOWING DESCRIBES A TYPICAL MODULE START AND SHUT DOWN SEQUENCE

- A) POSITION THROTTLE LEVER TO START
- B) TURN POWER SWITCH TO ON – THIS ILLUMINATES ALL THE CAUTION/WARNING LIGHTS EXCEPT THE CHIP LIGHT TO VERIFY THAT BULBS ARE OPERATIONAL.
- C) PUSH AND RELEASE RE-SET BUTTON – THIS CLEARS THE CAUTION/WARNING LIGHTS.
- D) SET PUMP CONTROL SWITCH TO AUTOMATIC OR MANUAL AS DESIRED
- E) SET PRESSURE DIAL TO 300 psi
- F) PUSH AND RELEASE START BUTTON – THIS INITIATES START SEQUENCE BY ENERGIZING STARTER MOTOR. WHEN 15 PERCENT SPEED IS REACHED IGNITION AUTOMATICALLY OCCURS. ENGINE ACCELERATES TO 60 PERCENT SPEED AT WHICH TIME THE STARTER AUTOMATICALLY SWITCHES FROM STARTER TO GENERATOR MODE
- G) WHEN 60 PERCENT SPEED IS REACHED SWITCH THE PRIME SWITCH TO ON AND HOLD IT UNTIL PRIME IS ACHIEVED, APPROXIMATELY 2 MINUTES.
- H) THEN ADVANCE THROTTLE AND PRESSURE DIAL TO THE DESIRED SETTING.
- I) TO SHUT DOWN MODULE REDUCE THROTTLE SETTING TO IDLE FOR TWO MINUTES THEN MOVE THROTTLE TO OFF AND TURNER POWER SWITCH OFF. IN AN EMERGENCY PUSH THE STOP BUTTON.

IN THE EVENT A PROBLEM OCCURS AND A CAUTION WARNING LIGHT IS ILLUMINATED IT WILL REMAIN ON UNTIL THE PROBLEM IS CLEARED UP. PUSHING THE RE-SET BUTTON WILL NOT CLEAR THE LIGHT IF MODULE IS RUNNING AND THE PROBLEM STILL EXISTS.

Figure 31. Typical start/stop sequence.

AUTOMATIC SEQUENCE

DURING

START

OPERATOR INITIATES START & STARTER ROTATES ENGINE	-	TIME ZERO
SPARK IGNITER ENERGIZED	-	15% SPEED (NORMALLY REQUIRES \approx 5 SEC. FAILURE TO ACHIEVE IN 15 SECS RESULTS IN ABORT & STARTER IS DEENERGIZED.)
FUEL VALVE OPEN-ENGINE STARTS & ACCELERATES	-	15% N, SPEED PLUS 3 SECS
STARTER SWITCHES TO GENERATOR MODE & IGNITER IS DEENERGIZED	-	60% N, SPEED (NORMALLY REQUIRES \approx 20 SECS. FAILURE TO ACHIEVE WITHIN 45 SECS. RESULTS IN ABORT- STARTER, IGNITER & FUEL VALVE ARE DEENERGIZED.)

FAULT ISOLATION PARAMETERS

DISCHARGE PRESSURE MUST REACH 20 PSI WITHIN 120 SECS OF START INITIATION	-	ENGINE REDUCED TO IDLE. "NO PRIME" LIGHT (AMBER) FLASHES
TURBINE OUTLET TEMPERATURE (TOT) DURING START MUST BE LESS THAN THE FOLLOWING RAMP: 927°C IN FIRST SEC TO 780°C IN 15 SECS.	-	ENGINE SHUTDOWN. TOT LIGHT (RED) IS ENERGIZED
TURBINE OUTLET TEMPERATURE (TOT) DURING RUN ($>$ 58% SPEED) MUST BE LESS THAN $>$ 780°C	-	ENGINE SHUTDOWN. TOT LIGHT (RED) IS ENERGIZED
PUMP WATER TEMPERATURE MUST NOT EXCEED 82°C	-	ENGINE SHUTDOWN. WATER TEMPERATURE LIGHT (RED) IS ENERGIZED
ENGINE OVERSPEED (105%)	-	ENGINE SHUTDOWN. OVERSPEED LIGHT (RED) IS ENERGIZED
METAL CHIPS INDICATED IN EITHER ENGINE OR PUMP LUBRICATION SYSTEM	-	ENGINE SHUTDOWN. CHIP LIGHT (RED) IS ENERGIZED
ENGINE OIL PRESSURE LESS THAN 40 PSI	-	ENGINE SHUTDOWN. ENGINE LOW OIL PRESSURE LIGHT (RED) IS ENERGIZED. (INHIBITED UNTIL 58% SPEED IS ACHIEVED)
PUMP OIL PRESSURE LESS THAN 40 PSI	-	ENGINE SHUTDOWN. PUMP LOW OIL PRESSURE LIGHT (RED) IS ENERGIZED (INHIBITED UNTIL 58% SPEED IS ACHIEVED)
ENGINE OIL TEMPERATURE EXCEEDS 102°C	-	ENGINE OIL TEMPERATURE LIGHT (AMBER) IS ENERGIZED
PUMP OIL TEMPERATURE EXCEEDS 143°C	-	PUMP OIL TEMPERATURE LIGHT (AMBER) IS ENERGIZED
FUEL LEVEL LESS THAN 1/3 FULL	-	LOW FUEL LIGHT (AMBER) FLASHES

Figure 32. Controller functions.

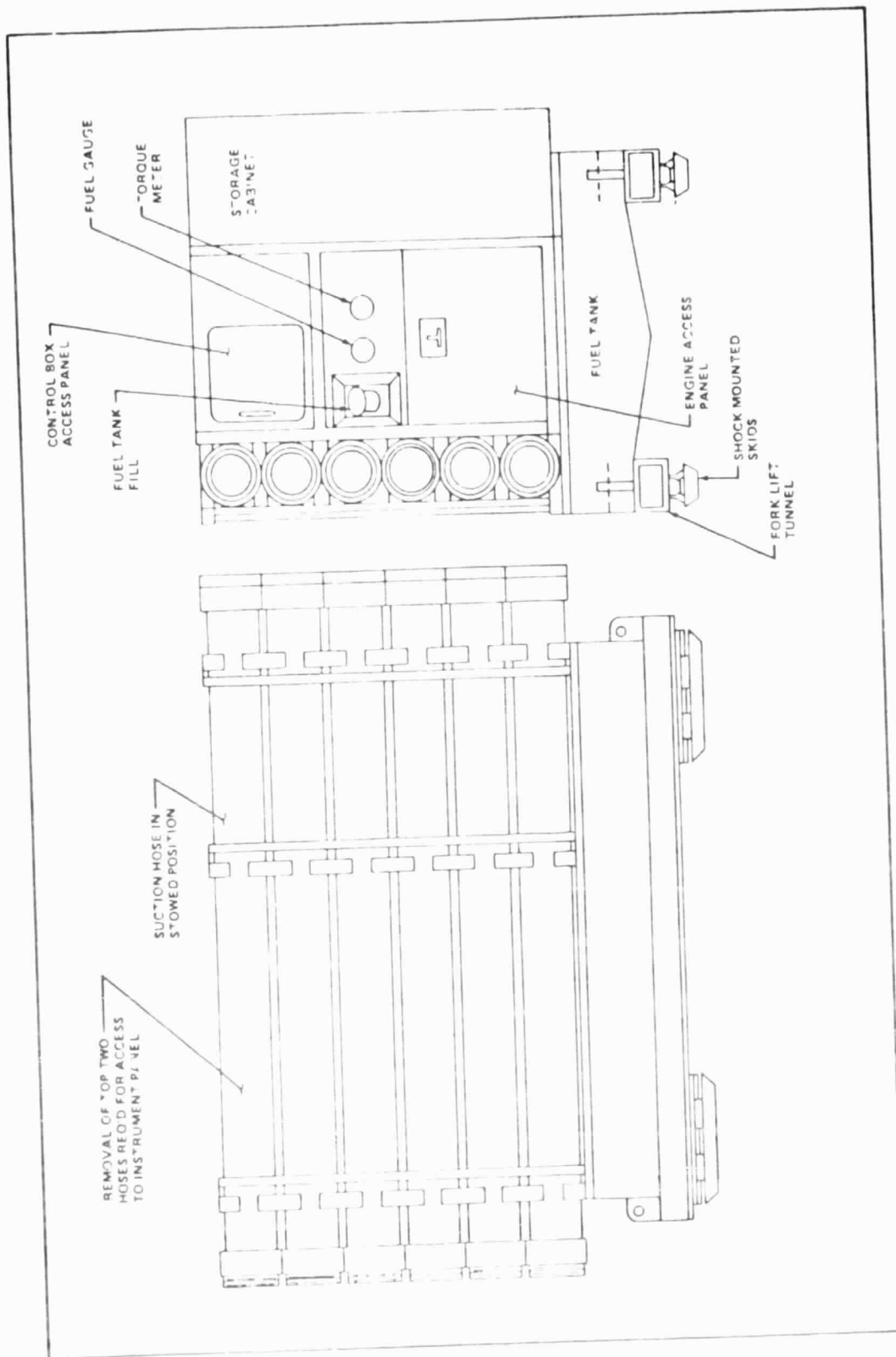


Figure 33. Module sketch with suction hose stored.

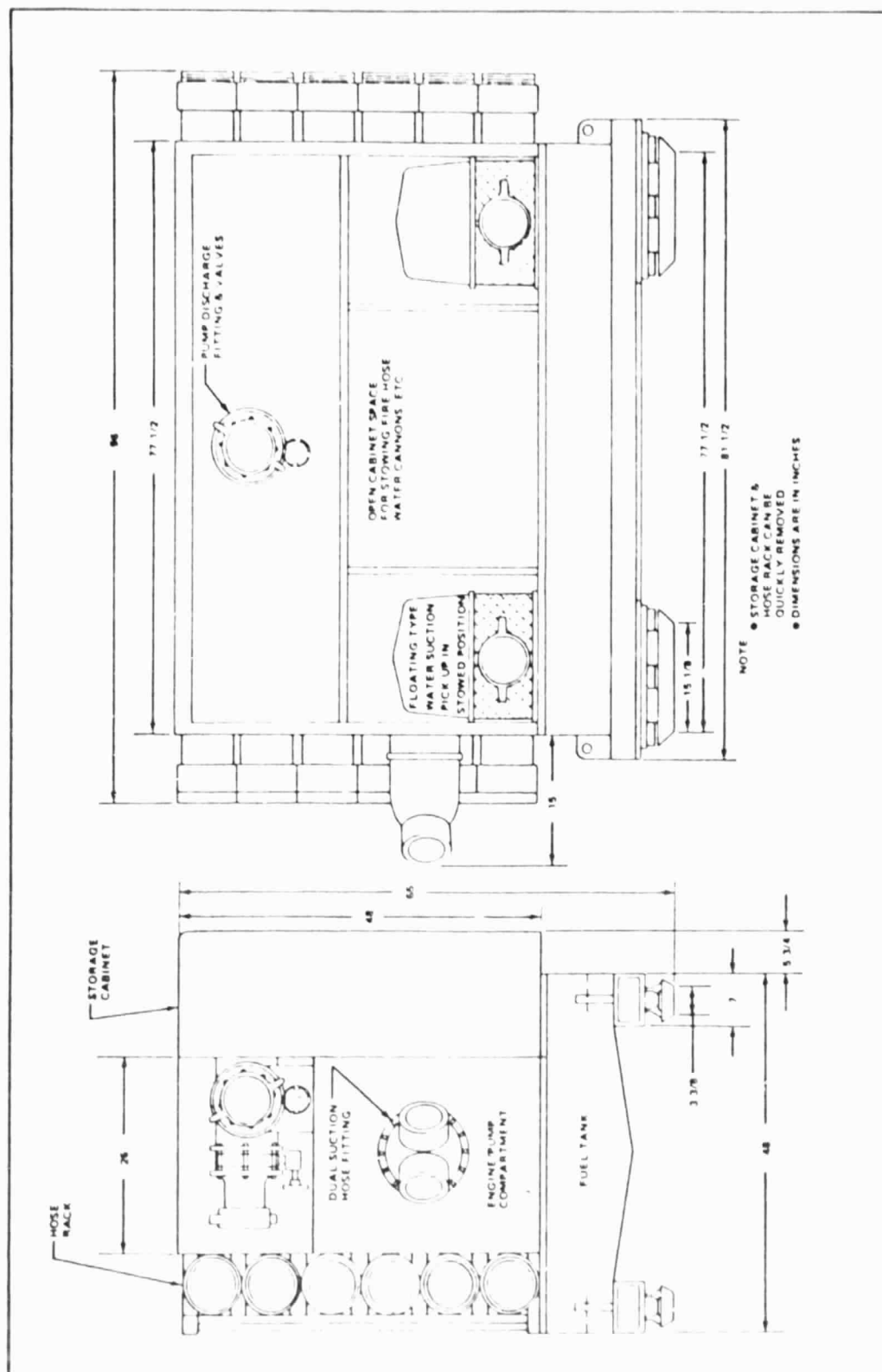


Figure 34. Module sketch with equipment rack.

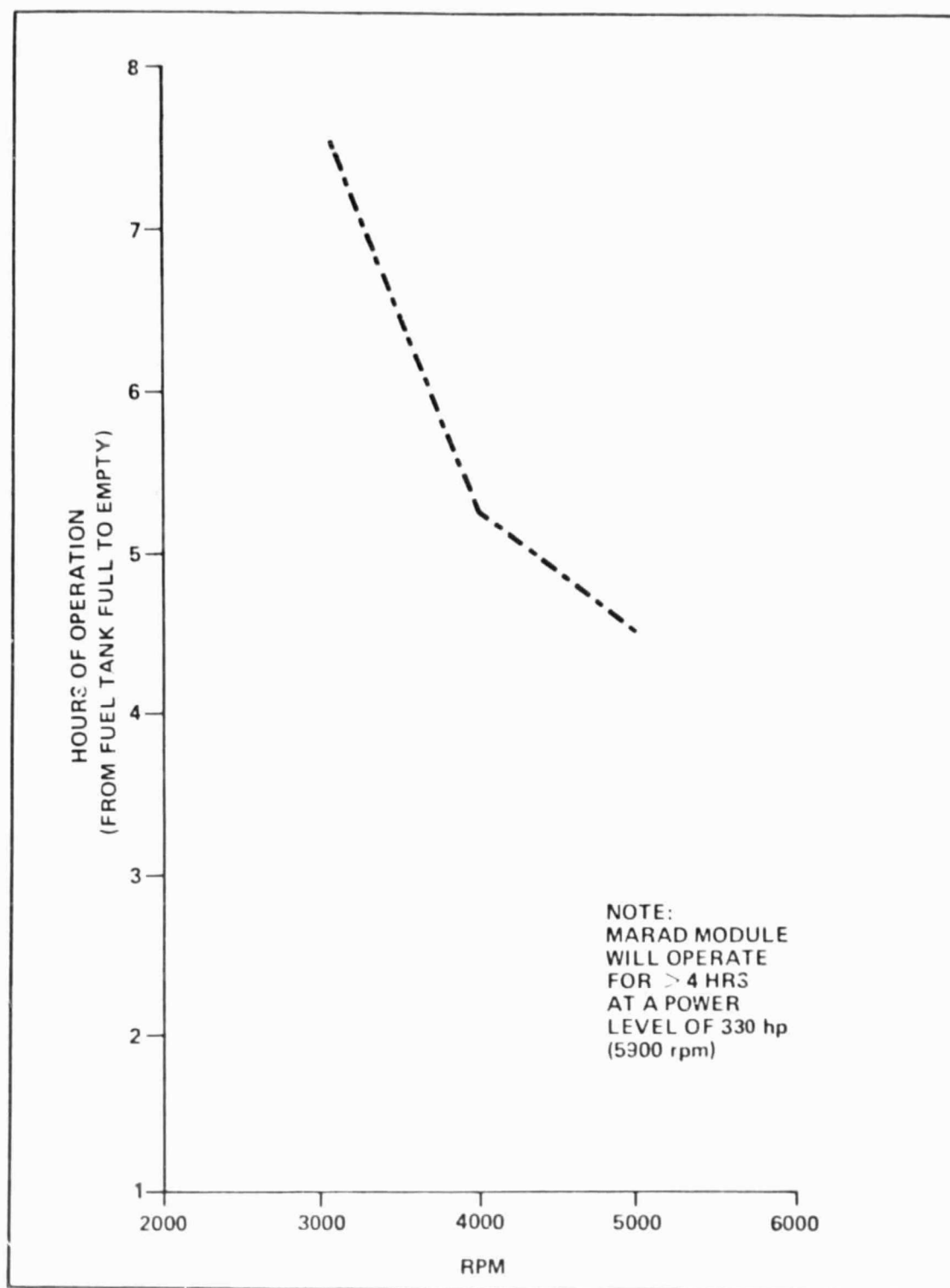


Figure 35. USCG module fuel consumption.

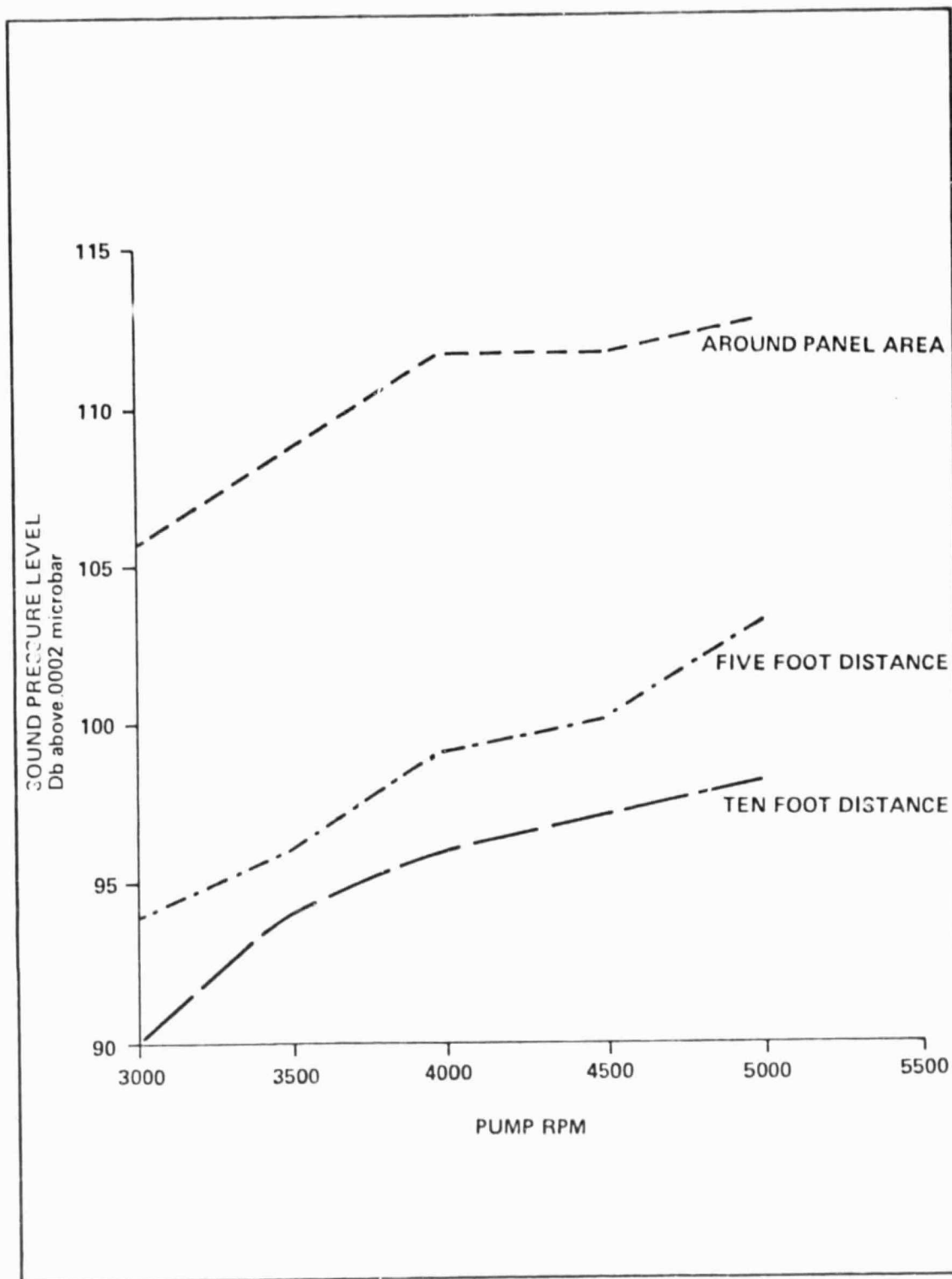


Figure 36. USCG module acoustic noise.



Figure 37. USCG boat, water cannons forward.

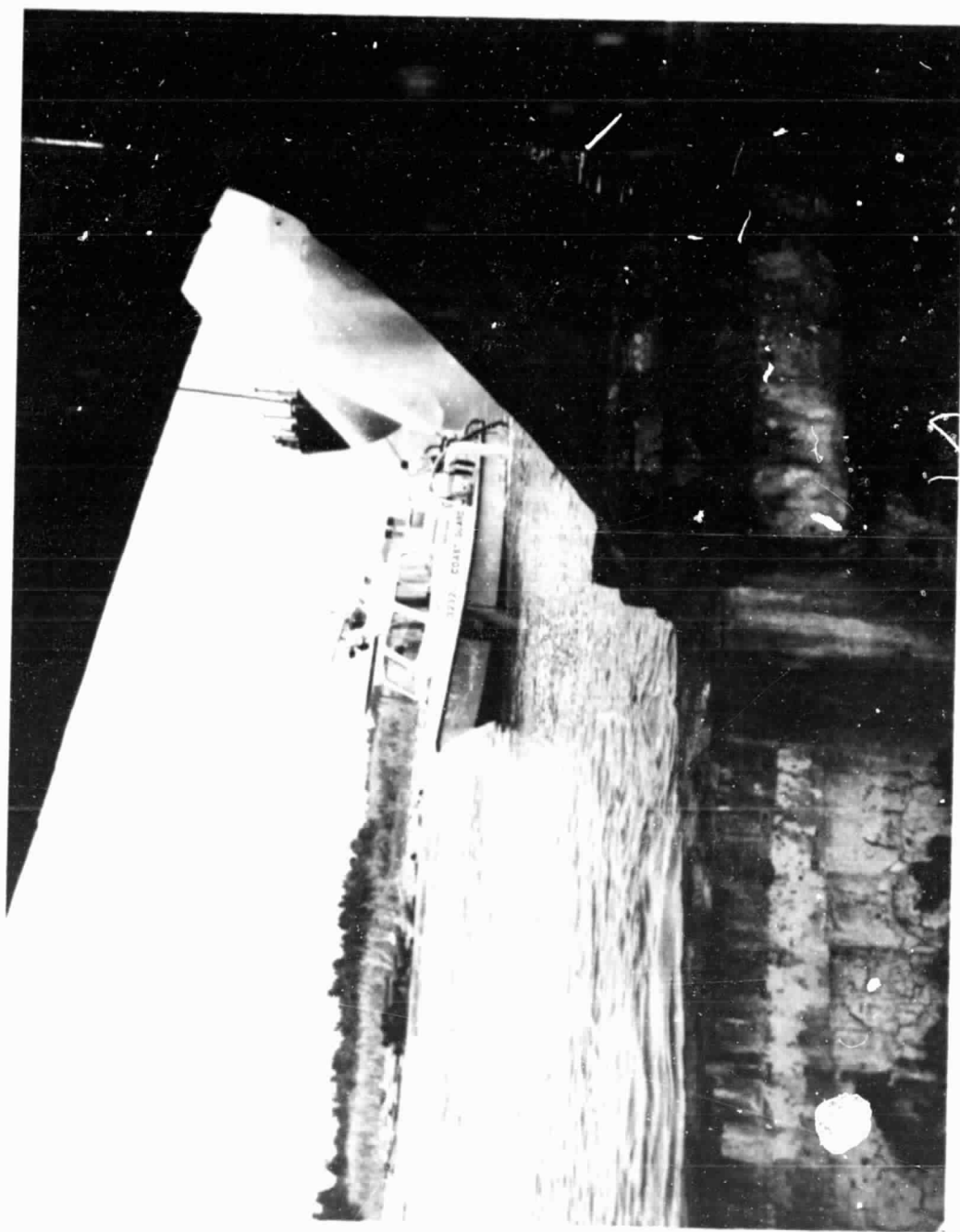


Figure 38. USCG boat, water cannons aft.

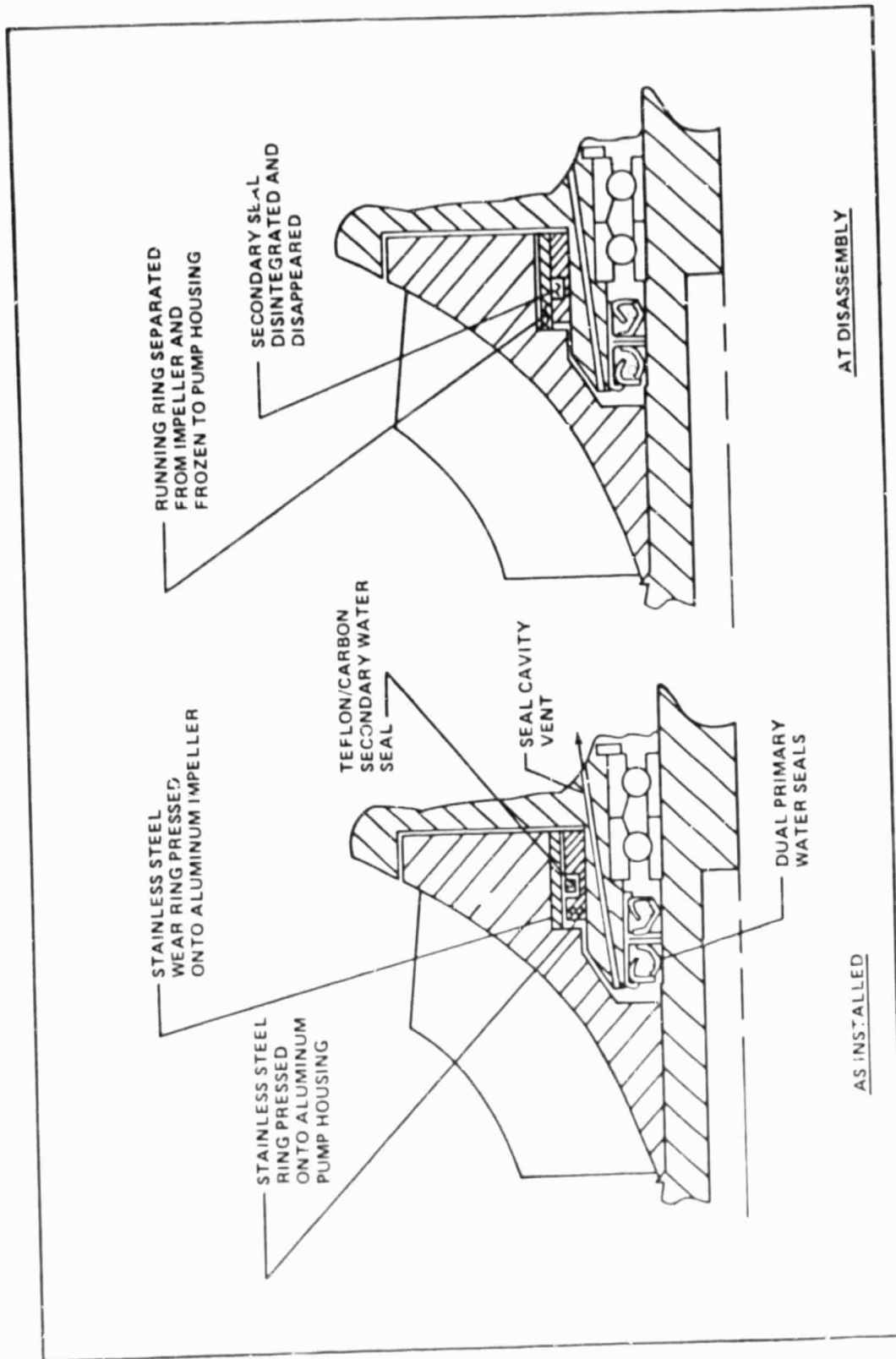


Figure 39. Main impeller secondary seal.

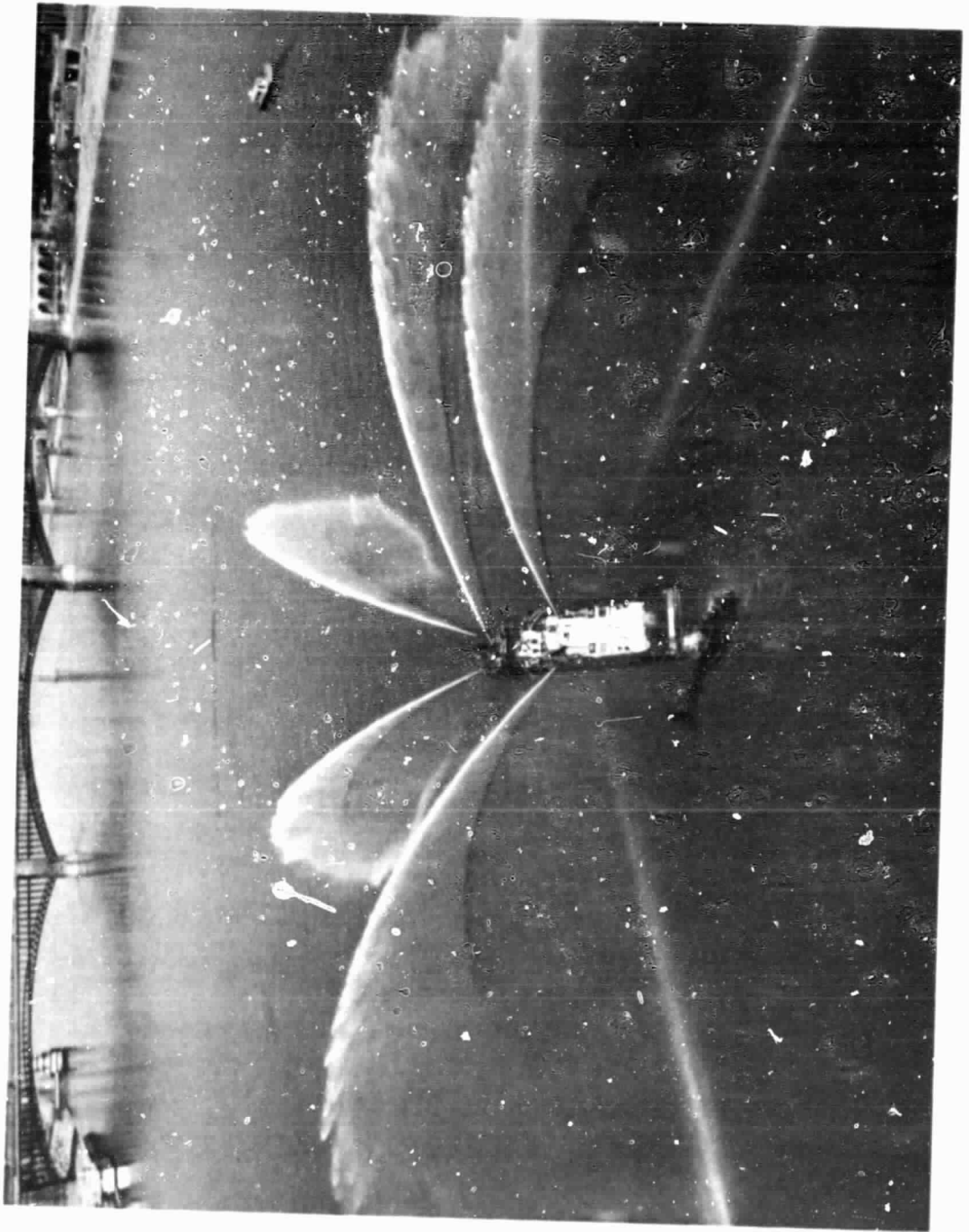


Figure 40. MARAD module on barge.

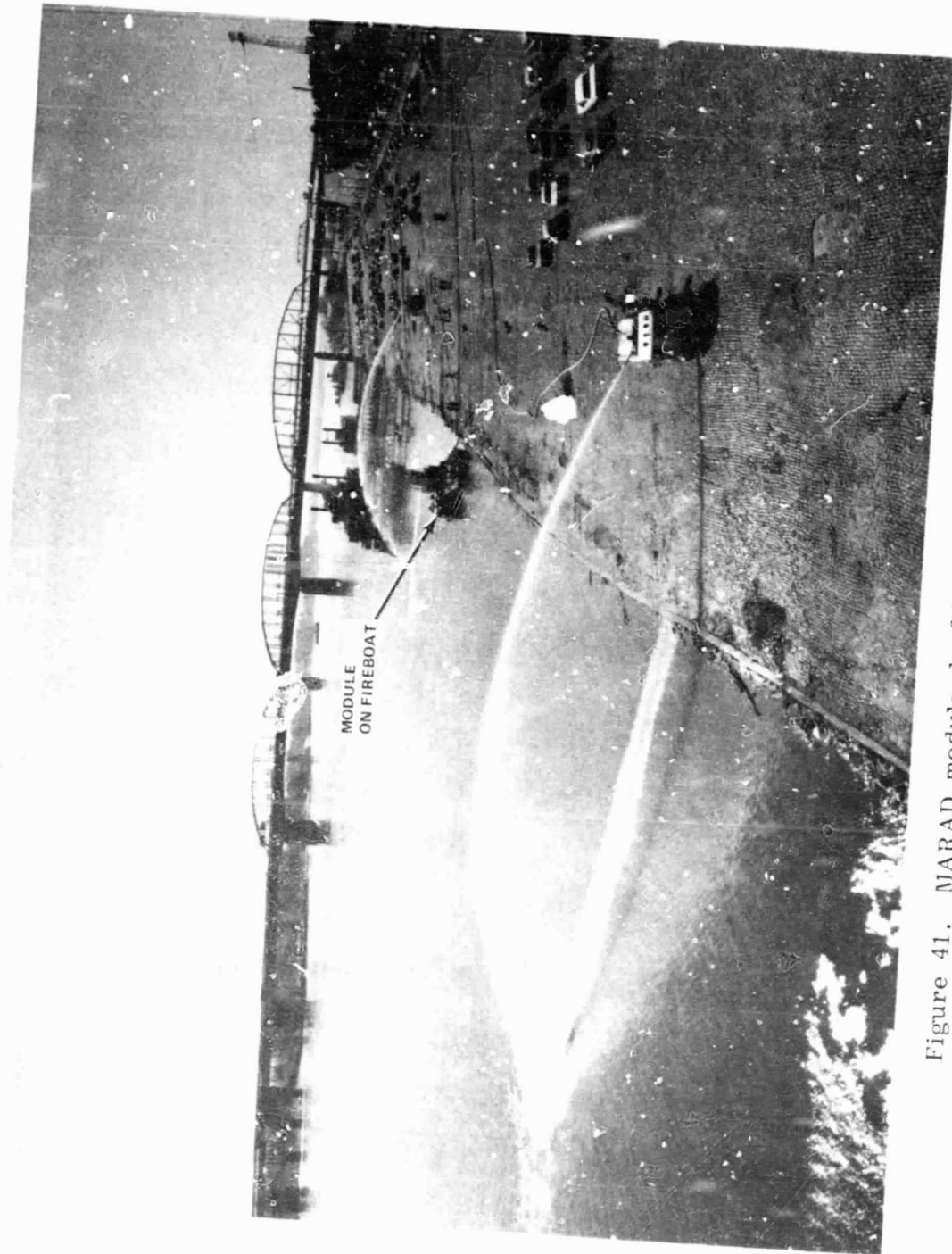


Figure 41. MARAD module drafting water to two pumps.

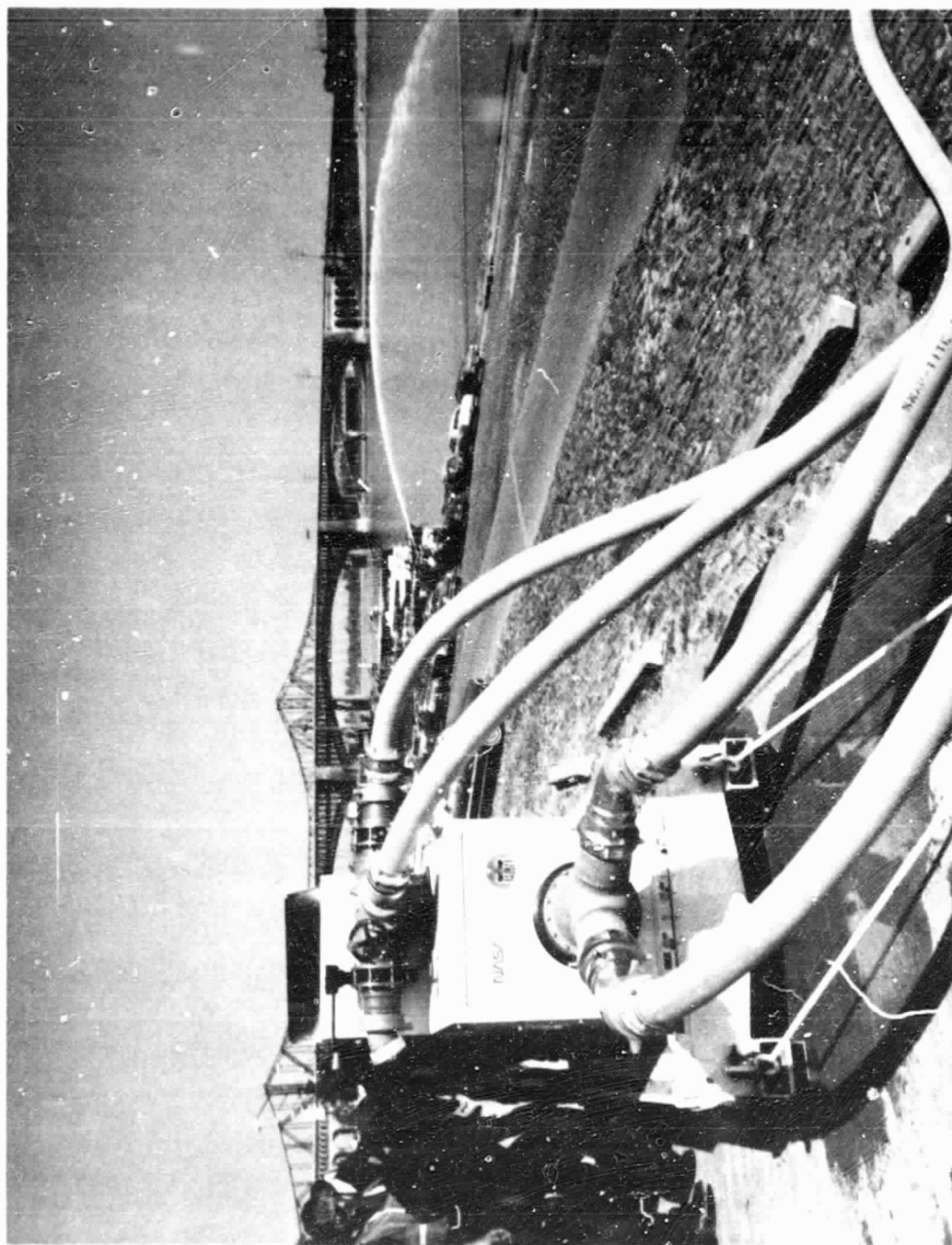


Figure 42. MARAD module pumping water from a hydrant.



Figure 43. MARAD module helicopter lift.

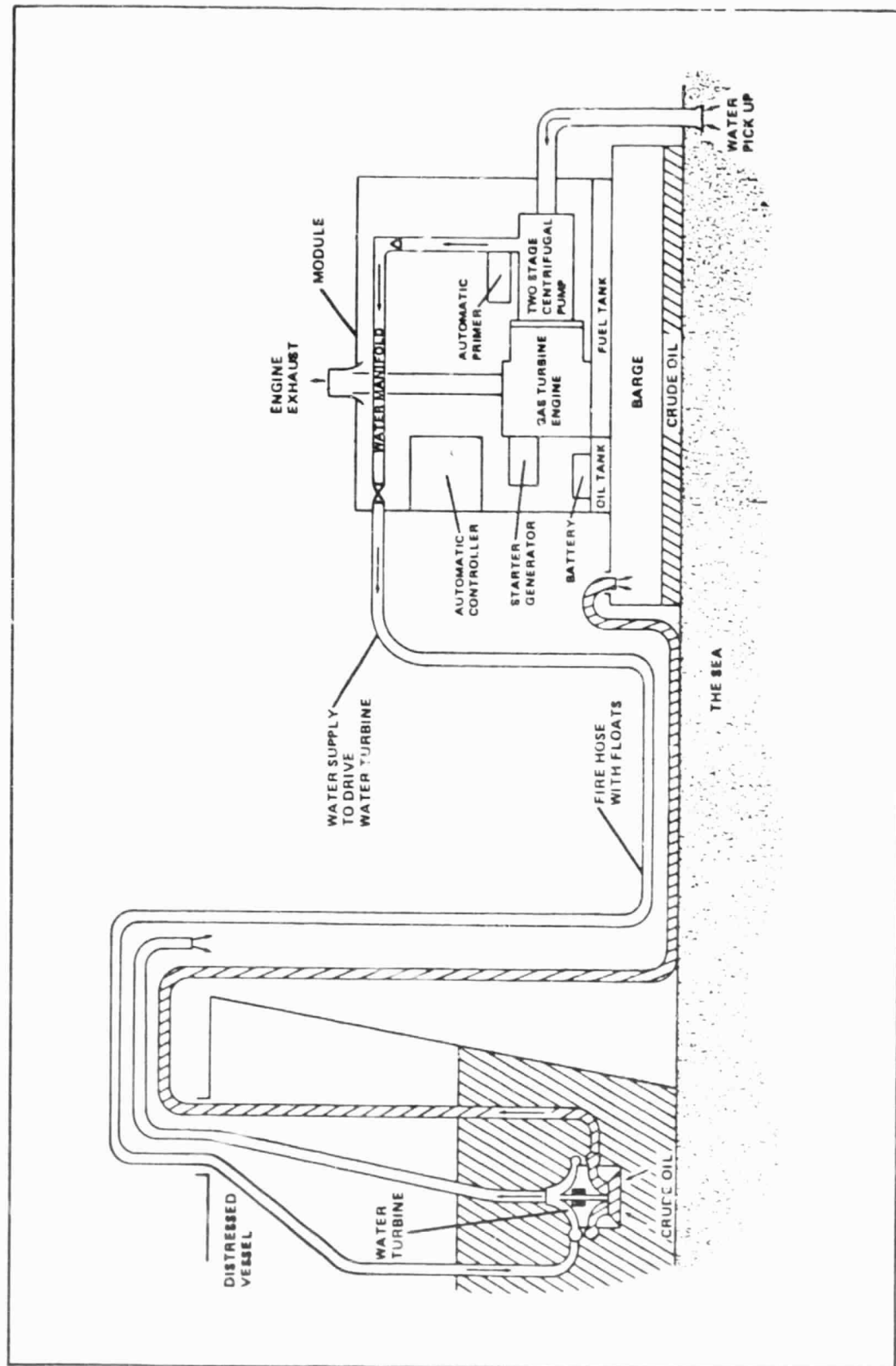


Figure 44. Oil off loading.

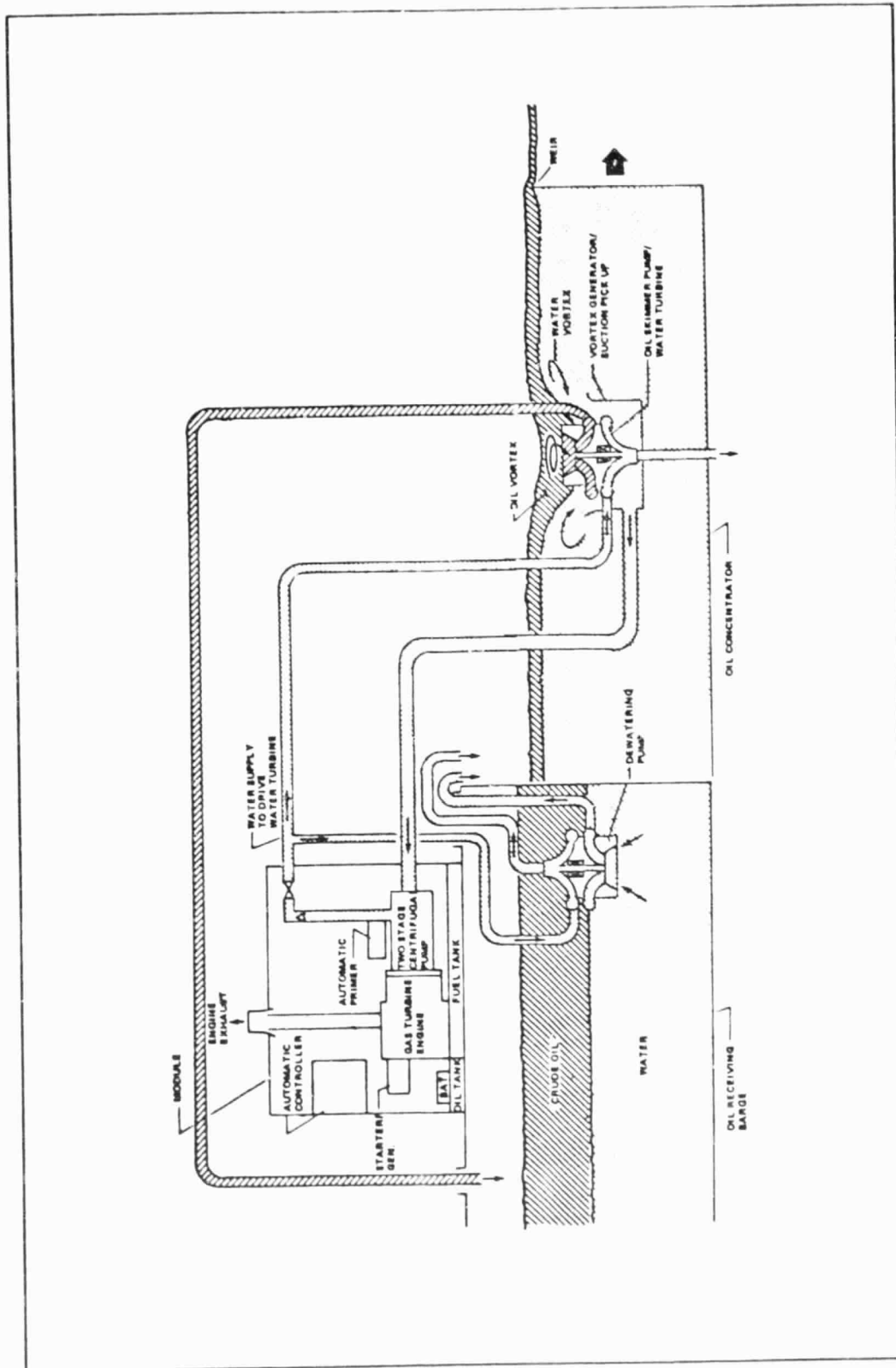


Figure 45. Oil skimmer system.

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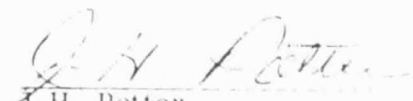
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APPROVAL

FIREFIGHTING MODULE DEVELOPMENT

By Ralph A. Burns

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification officer. This report in its entirety has been determined to be unclassified.



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